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Why This Flip Wasn't a Flop: What the Numbers Don't Tell You About Flipped Classes

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Abstract

This paper details the conversion of a large, required Civil Engineering fluid mechanics course into a more student-centered, active learning-oriented course through the flipping of one lecture per week. In the flipped class, students collaboratively solve homework problems in groups while receiving "expert" feedback from instructors and TAs. To offset the lost lectures, some course material that has been delivered in traditional lectures has been placed online in the form of short videos and textbook readings, with low-stakes quizzes for assessment.

Student learning gains were quantitatively assessed by comparing quiz and final exam scores for three semesters (1 pre-flip and 2 post-flip). To maintain some element of consistency across the course transformation, a comprehensive, multiple-choice final exam has served to provide quantitative metrics on which the course improvement can be gaged. In addition, quiz questions remained relatively similar across semesters. One-way ANOVAs revealed a statically significant difference on quiz performance, with post-flip students performing better than those in pre-flip semesters. In addition, students in the final iteration of the course transformation significantly outperformed previous students on final exams by about 7%.

Taken together, the numbers suggest that the process of flipping a large fluid mechanics course is associated with small but positive improvements to quiz and final exam performance. However, it is best to rely on other indicators beyond course performance in order to more accurately depict the impact of a course transformation. To supplement the results of the quantitative analyses, student comments about the course and instructor observations of the transformation implementation were assessed. Students found the work sessions to be very effective, enjoyed collaborating with peers and the instructor, and thought the online videos were helpful. The instructor indicated that the benefits of the flipped class include the following: heightened student engagement during class periods; greatly increased instructor awareness of student perceptions, challenges, personal issues, and conceptual bottlenecks; eventual reduction in instructor preparation time; improved instructor-student relationships; and a better focus on more important course objectives.

Introduction

This paper details the progressive conversion of a large, required Civil Engineering fluid mechanics course, "CE 300", into a more student-centered, active learning-oriented course. The course overhaul resulted in the conversion of one lecture per week into a flipped class in which students collaboratively solve homework problems in groups while receiving "expert" feedback from instructors and TAs.

The transformation of CE 300 was inspired, in part, by the participation in a large-scale campus-wide intervention intended to help faculty redesign their courses in order to make them more student-centered.[1] For CE 300, the major goal of its transformation was to incorporate more active learning strategies into the course, which ultimately led to a restructuring of the class format. In what follows, we review the literature on which this course transformation was based,

describe the specific changes made to CE 300, and quantitatively and qualitatively assess the effectiveness of this flipped class from both the student and instructor perspectives.

Active Learning

Pedagogical researchers have come to an agreement that implementing a traditional lecture style is not the most effective way to improve student learning. Studies show that this form of passive learning is actually associated with a decrease in course performance.[2,3] Conversely, *active* learning includes the use of pedagogical strategies that encourage student engagement with course material. Research shows that when students reflect, discuss, ask questions, or pose and resolve problems, they stand a better chance of actually learning and understanding course material, compared to a traditional lecture wherein they passively receive information from the instructor.[4] More specifically, when students are actively involved in their learning process, they receive a host of benefits including improvements in retention of information,[5,6] exam performance[2,7] and thinking and writing skills[8] to name a few.

Of course there are some challenges associated with implementing effective active learning strategies. Instructors are weary of implementing changes that will add to their already heavy workload.[9] This process may become even more time-consuming when trying to effectively incorporate these techniques in large enrollment classes.[10] Some instructors feel that it is difficult to hold meaningful discussions with such a large number of students or that the physical space does not easily allow for students to collaborate with others.[11,12] Perhaps the most frequently cited challenge to active learning, regardless of class size, is a concern that there will not be enough time to sufficiently cover course content.[10,13] One solution that has been employed to address the above challenges, especially within STEM disciplines, is to flip the course.

Flipped Courses

Flipped courses, also referred to as replacement model or hybrid courses, involve the placement of course material online (e.g., videos, additional readings) that students must digest in order to be prepared for the following class.[14] Posting lectures online for students to watch before class, as opposed to having them simply read the textbook, has proven to be beneficial to students in that they come to class more prepared,[15] and perform better on class discussions[16] and tests.[17]

By placing less complicated material online, more class time is available that can be dedicated to active learning. For STEM courses, in particular, it is especially important to use this extra time to allow students to engage in inquiry learning wherein students are "presented with questions to be answered, problems to be solved, or a set of observations to be explained".[18,19] This is why flipped courses have become increasingly popular in engineering departments. In their review of the engineering education literature, Velegol and colleagues state that dedicating class periods to work sessions facilitates an increase in peer and student-teacher interactions, the use of higher-order thinking (e.g., applying and analyzing), and the ability to consume course content at their own pace (e.g., they can re-watch online videos).[20] During in-class work sessions, the instructor can also identify common problems, which can be addressed to the entire class. Velegol et al.[20] conducted a case study of an environmental engineering course that echoed their review of the literature. Although they did not see improvements in course performance, when asked

specifically about their preferences for flipped versus traditional classes students reported that they prefer flipped classes because they can tailor the learning experience to their own needs and they appreciate the additional opportunities they have to interact with instructors and peers.

Of course no two flipped engineering classes are exactly alike. As such, educators can benefit from learning about the variations in flipped courses from a range of different engineering classes and what the subsequent outcomes are. In addition, soliciting feedback from students regarding their perceptions of the course in a more general fashion can elicit commentary on elements of the class they found most salient, as compared to asking more directive questions geared specifically towards perceptions of flipping the course.

In sum, the purpose of this paper is to test the effectiveness of a flipped civil engineering course in terms of student performance, while also identifying student perceptions of the flipped class format. In addition, this paper details the instructor's experience with flipping the course and highlights observed benefits not evident in the quantitative data. Next, we present an overview of the CE 300 course and its transformation along with the methodology used to assess this flipped course.

Course transformation

CE 300 has standard first-level fluid mechanics content that includes fluid properties, hydrostatics, shear stress, the Bernoulli Equation, control volume analysis, dimensional analysis, and open channel flow. The three credit hour course has enrollment that varies between approximately 90 and 175 students, and is dominated by junior and senior civil engineering students (about 60%), with a smaller percentage of students typically from agricultural and biological engineering and other engineering disciplines. Most (>80%) students enrolled in CE 300 are also enrolled in a companion one-credit laboratory course, but there are no recitation sections for the course.

Flipping CE 300

During the Fall 2013 semester, CE 300 was structured as three 50-minute lectures per week, with these lectures conducted in the traditional sense (i.e. the instructor lecturing and students taking notes). The instructor attempted to incorporate some active learning techniques into the classroom by having students solve a few problems in class. To accommodate this extra demand on in-class time, the instructor shifted the delivery of some course content out of the classroom. Topics selected for out-of-class delivery were the most straightforward topics in the course such as definitions and very simple formulae (i.e. topics and concepts that can easily be conveyed by a handout, textbook reading, or short video). An example of such a topic is the ideal gas law, which in a civil engineering fluid mechanics course is a straightforward formula ($p = \rho RT$) that is effectively explained by most textbooks.

During the same semester (Fall 2013), the instructor held optional "homework help sessions" during the evenings, where students would work on their homework in a large classroom (alone or in groups as they chose), and could ask individual questions of the teaching assistants and instructor. This homework help session was incredibly beneficial for the students that could attend it (as voiced in the students' end-of-semester course evaluations reported later in the

paper), but only about 20% of the class attended these optional sessions. The instructor saw these sessions to be so advantageous to student learning that in Fall 2014 and Spring 2015, one of the three weekly lectures for the course was formally converted to a flipped class that was held in a large, active learning classroom consisting of tables that seated 5-10 students each. The entire class period was dedicated to allowing students to work together on either sample problems (Fall 2014) or homework problems (Spring 2015), while the teaching assistants and instructor roamed the classroom asking students if they needed help, and answering questions individually when students raised their hands. Attendance was taken during some of the flipped classes to motivate students to attend, but this did not count towards their final grade. Students were allowed to sit wherever they liked, but were encouraged to work with other students (nevertheless, several students chose to work alone). After the first several flipped classes, students generally sat in the same groups for the remainder of the semesters.

In addition to the work session held during one of the class periods, the instructor continued to include active learning techniques during the remaining two weekly lecture periods. This increase in active learning required the instructor to place even more course content online, in effect tripling the amount of instructor-made videos. Companion textbook sections were still provided to students whose learning styles favored textbook delivery over videos.

Assessments

In order to ensure students were consuming the out-of-class content (e.g., videos, readings), they were assigned low-stakes online Blackboard-administered quizzes (3-10 questions) on the material that included multiple choice and/or randomized calculation questions. Quizzes comprised between 5-10% of the students' grades during the three semesters described in this paper.

In addition, a multiple-choice, comprehensive final exam was created for the course in order to (1) solidify and consolidate student learning of the most fundamental concepts in the course; and (2) provide assessment data that would allow for the evaluation of pedagogical techniques and in turn guide future improvements to the course. This approximately 25-item exam was styled after the Fundamentals of Engineering (FE) exam, in that the format of the test was multiple choice, and stressed only the absolute essential material in the course. It differed slightly from the FE exam in that not all questions involved calculations; some questions were conceptual, requiring students to apply basic concepts to situations or diagrams presented (for example: "In the diagram shown, where is pressure greatest?").

Quantitative analyses: Grades and student course ratings

Participants

The sample consisted of 377 students enrolled in the CE 300 fluid mechanics course during the Fall 2013, Fall 2014, and Spring 2015 semesters. See Table 1 for a list of student characteristics across semesters. In addition, 209 students in total completed the course evaluations (55% in Fall 2013; 39% in Fall 2014; 84% in Spring 2015).

Table 1. Demographic data for students enrolled in CE 300

	Fall 2013	Fall 2014	Spring 2015	Total
Age	21.86	22.01	21.78	21.91
Gender				
Male	67.50%	69.80%	75.50%	70.60%
Female	32.50%	30.20%	24.50%	29.40%
Ethnicity				
White	68.40%	63.60%	56.10%	63.10%
International	16.20%	25.90%	26.50%	23.10%
Hispanic/Latino	4.30%	3.70%	5.10%	4.20%
Asian	6.00%	1.90%	4.10%	3.70%
Black/African American	0.00%	1.20%	3.10%	1.30%
Mixed Race	2.60%	1.90%	2.00%	2.10%
Unknown	2.60%	1.90%	3.10%	2.40%
Enrollment	117	162	98	377

Materials

Student Performance

Two criteria were used to assess student performance in the class: average quiz percentage and the comprehensive final exam percentage. As previously mentioned, these two assessments remained consistent across all three semesters in terms of format and content.

Course Evaluations.

Data were collected through the CoursEval system. A general question about the course, *Overall, I would rate this course as*, and instructor, *Overall, I would rate this instructor as*, were included using a 5-point scale (*1* = very poor; *5* = excellent). In addition, four items were included to assess student perceptions of skill gains (e.g., *As a result of your work in this class, what gains did you make in the skill of performing basic fluid mechanics calculations on engineering systems to estimate pressures, velocities, forces, and stresses?*) using a 5-point scale (*1* = I gained nothing at all; *5* = I gained a great deal). Internal consistency for perceptions of skill gains was strong (Cronbach's $\alpha = .89$). Students also responded to two open-ended questions: (1) *What is something/are some things that the instructor does well, e.g., something you hope that the instructor will continue to do in the class in the future?*; and (2) *Make a suggestion(s) for improving the course (a criticism alone is not helpful; tell your instructor how you would fix any problem).*

Procedure

Data from the course evaluations were collected once each semester had ended. Students in the Fall 2013 course participated in the traditional version of the course while those in the Fall 2014 and Spring 2015 courses participated in the flipped version. There were no differences in GPA, age, or gender between students in the traditional versus flipped courses. However, students in the flipped sections had slightly more International students.

Quantitative results

Analyses were run to test whether differences existed between a traditional versus flipped course on student performance, course evaluations, and perceptions of learning. One-way analyses of variance were conducted with semester (Fall 2013-traditional; Fall 2014-flipped; Spring 2015-flipped) serving as the independent variable and quiz average percentage, final exam percentage, course rating, instructor rating, and perceptions of skill gains serving as dependent variables.

Quiz average

There were significant differences on quiz average scores across semesters, F (2, 374) = 7.60, p < .01; partial η^2= .04. Pairwise comparisons revealed that quiz average in the Fall 2013 semester significantly differed from both the Fall 2014 and Spring 2015 semesters at the p <.01 level. Inspection of mean scores suggest that students in the Fall 2013-traditional semester (M = 78.15, SD = 18.07) had lower quiz averages compared to those in the Fall 2014-flipped (M = 86.29, SD = 16.01) and Spring 2015-flipped (M = 84.50, SD = 19.36) classes.

Final exam

There were significant differences on final exam scores across semesters, F (2, 374) = 6.35, p < .01; partial η^2= .03. Pairwise comparisons revealed that final exam scores in the Spring 2015 semester significantly differed from both the Fall 2013 and Fall 2014 semesters at the p < .01 level. Inspection of mean scores indicate that students in the Spring 2015-flipped semester (M = 77.29, SD = 16.64) had higher final exam scores compared to those in the Fall 2013-traditional (M = 69.91, SD = 15.49) and Fall 2014-flipped (M = 70.89, SD = 16.94).

Course evaluations

There were no significant differences on course rating, F (2, 206) = .27, p = .771; partial η^2= .003, instructor rating, F (2, 206) = .30, p = .75; partial η^2= .003, or perceptions of skill gains, F (2, 205) = 1.01, p = .37; partial η^2= .01 across semesters. Table 2 displays means scores for all semesters.

Table 2. Mean scores for course rating, instructor rating, and perceived skill gains

	Fall 2013 *M* (*SD*)	Fall 2014 *M* (*SD*)	Spring 2015 *M* (*SD*)
Course rating	4.72 (.45)	4.65 (.51)	4.68 (.59)
Instructor rating	4.94 (.24)	4.92 (.27)	4.90 (.30)
Perceived skill gains	4.57 (.56)	4.44 (.57)	4.55 (.54)

Note. M = Mean, SD = Standard deviation

Conclusions: Quantitative analyses

Although the flipped format did not have an effect on course rating, instructor rating, or perceived skill gains, there were significant differences across semesters regarding student performance. Students in the flipped semesters of CE 300 outperformed those in the traditional semester on quiz average percentage, which may have been due to the increased association of quiz material with videos created for the course. In addition, students in the Spring 2015 flipped

semester scored higher on the final exam compared to those in the previous two semesters. This difference occurred despite the fact that course and instructor ratings were already very high, leaving little room for improvement. Given that there were also no differences in student characteristics (e.g., GPA, gender, etc.), one possible explanation is that in the second iteration of the flipped course, the instructor's implementation of this type of course format may have improved, thus resulting in better student performance.

While the impact of the flipped class on student performance is promising, the relatively small effect sizes suggest that other factors are also influencing differences in student performance beyond the course format. This is not surprising given the difficulty of relying on fallible assessment data as an indicator of learning improvement (for a review see reference [20]). Thus, it is useful to turn to other types of data to supplement the quantitative analyses in order to better assess whether this course transformation had a meaningful impact.

Qualitative analyses

In order to supplement the findings from the quantitative analyses, and to give a broader view of the impact of a flipped course beyond what can be depicted by numbers alone, qualitative analyses were conducted. Specifically, student comments about the course were coded for themes that relate to flipped courses. In addition, a summary of instructor observations about the transformation is provided.

Student feedback

Student responses to the two open-ended questions that appeared on the course evaluations were coded for themes. Given the broad nature of the open-ended questions, students commented on a variety of aspects of the course, including grading, the textbook, personality characteristics of the instructor, and so on. For the purpose of this paper, we report only on the themes that speak directly to flipped courses.

For the Fall 2013 semester, 49 students responded to the open-ended questions. In Fall 2014, 46 students responded and in Spring 2015, 55 students provided comments. Of those student comments, three prominent themes emerged: (1) enjoyment of the work sessions, (2) improved interactions with peers and the instructor, and (3) enjoyment of the online videos.

As previously mentioned, the instructor held voluntary homework help sessions during the traditional Fall 2013 course. These sessions later became a required part of the course, replacing one lecture per week during the Fall 2014 and Spring 2015 semesters as the flipped class. Students in all three semesters commented on how much they enjoyed the work sessions, with those in the flipped courses commenting at a higher frequency (Fall 2013 = 16%; Fall 2014 = 39%; Spring 2015 = 22%). As one student in the Fall 2014 semester noted, *"I liked having the two types of lectures: the actual lecture twice a week and then the practice class once a week. I think it helped me to better understand the material, since we did related work and had ample amounts of help."* Another student stated, "*Please continue with your method of using one class as a problem solving class…these were really helpful."* (Fall 2014)

In addition to appreciating how helpful the work sessions were in terms of aiding in their understanding of the material, they also commented on how these sessions increased their ability

to connect with their classmates and the instructor. As a student from Fall 2013 stated, *"The [voluntary work sessions] are extremely helpful both for receiving help and for working with other people."* Other students mentioned that it was advantageous to learn from their peers. For example, a student in the flipped Fall 2014 course commented, *"Having a designated class work session where you can work together in groups helps you learn from fellow students."* In addition, flipping the class allows the instructor to get to know students better, mainly by having more time to sit down with them individually and help them one-on-one, despite the large class size. A student from the Spring 2015 flipped class said, *"[The instructor] gets to know everyone [sic] of his students in at least one way, which is impressive with about 100 students. He asks if anyone needs help, and is not afraid to take a pencil out and work through a problem with you."*

Finally, while students in the traditional Fall 2013 course did not comment on the online videos they watched outside of class (most likely because there were fewer videos that semester), those in the flipped courses felt they were especially helpful. For example, one student from Fall 2014 said, *"I especially liked it when he put on helpful videos going over the concepts on blackboard. They were incredibly useful."* Some students noted that the videos helped them perform better on quizzes. For example, one student from Fall 2014 said, *"I also loved the quizzes we had and the videos that accompanied them. They were super interesting and short enough to keep my attention that I felt like I really learned from them."* Another student from Spring 2015 encouraged the use of videos by saying, *"Continue making more of the videos for the quizzes as those were extremely helpful to help learn the topics a little more in detail."* This supports the quantitative results that found those in the flipped semesters had higher quiz averages. Given that there were more online videos in the flipped classes compared to the traditional class, the videos appear to be an effective strategy to help students learn course material as evidenced by their performance on quizzes.

In sum, students across three semesters commented on the usefulness of the work sessions, the ability to work with peers and the instructor, and helpfulness of the online videos. The enjoyment of the work sessions and online videos appear to be especially salient to students in the flipped class as demonstrated by the higher frequency of comments regarding these topics. It should be noted that while students had an opportunity to make suggestions to improve the course, they did not report any criticisms of these elements of the class. In other words, students had nothing but positive things to say about the work sessions, extra opportunities to work with their peers and get to know their professor, and the online videos. Taken together, the students felt that these elements of the course were beneficial to them and should be continued in subsequent semesters.

Instructor observations

Until now we have highlighted the influence that flipped courses have on student outcomes (e.g., performance, perceptions), but there are also several benefits to instructors that have not been extensively documented in the literature. Many of these benefits arise from the interactions between the instructor and the students as the instructor circulates the room to answer questions and help students, either individually or in small groups. Additional benefits arise as a result of the logistical changes associated with flipping a class. In total, these benefits include:

- Increased teaching satisfaction from one-on-one and small group interactions with students
- Ability to directly perceive and address common learning bottlenecks
- Eventual reduction in teaching workload
- Flipped format necessitates a focus on key course learning objectives

Enhancement in teaching satisfaction

One unexpected instructor benefit to flipping the class was increased instructor teaching satisfaction. In the present study, the instructor found the flipped class to be immensely satisfying, much more so than a traditional lecture, due to the myriad student interactions during the class period. The increased instructor satisfaction was due to several factors.

During the flipped class, students were highly engaged with course material, working in groups on homework problems. The instructor could clearly observe this engagement as students discussed problems with their classmates, and taught each other how to solve the homework. This is contrasted with a traditional lecture, for which the instructor's enthusiasm is often met by rows of disengaged students. For the instructor, it was exciting and refreshing to see high student involvement with the subject matter.

Students benefited from the engaging learning environment because it provided an opportunity for more of their questions to be answered. Simultaneously, the instructor found it rewarding to see most of these interactions result in student "Ah-ha!" moments. This type of student interaction is fun and invigorating, as opposed to a traditional lecture in which there is often very limited, and very unnatural interactions with students (e.g. loaded questions asked in front of a large audience, which can facilitate artificial interpersonal interactions).

Teaching satisfaction also increased because the flipped class allowed for greater opportunities for the instructor to get to know individual students better, which is especially challenging in large classes. As highlighted in some of the student comments, students enjoyed having more opportunities to connect with their instructor, and this proved to be equally as rewarding for the instructor. This interaction also had an important carry-over to the rest of the course; the classroom dynamic in the traditional lectures for the course was greatly improved because the instructor and students were more comfortable with one another, and additionally students were more willing to contact the professor to ask for additional help outside the classroom because of these improved relationships.

Identification of learning bottlenecks

Beyond increased teaching satisfaction, the instructor found the flipped class to be very useful in understanding "bottlenecks" that were causing learning problems for students. Some of these bottlenecks were conceptual in nature; for example, students not understanding how to draw an appropriate control volume for a problem. But some of the bottlenecks were more logistical in nature, such as the instructor forgetting to provide a water depth that was needed in a homework problem, and students assuming that the problem could be solved as-is. In a normal classroom setting, students would struggle with the above issues outside the classroom – mostly unbeknownst to the instructor, as many students are reluctant to ask questions. In the flipped

class setting, the instructor was able to quickly realize that there was a common problem holding back students, and would give a short announcement clarifying the common issue.

Identifying issues through student interactions made it easier for the instructor to be more autonomy-supportive. For example, as a result of interactions with international students during the flipped classes, the instructor was able to perceive that one of the primary bottlenecks for many of these students was not the fluid mechanics concepts being taught in the course, but rather language difficulties associated with being non-native English speakers. Many of these students had relatively poor oral English skills – primarily with listening - and were therefore having great difficulties with material that was delivered only orally during lectures and videos. Realizing this, the instructor then made an effort to more consistently reference the appropriate textbook sections for lectures and quizzes; and while previously created videos could not be changed during the semester due to time constraints, the instructor realized the importance of captioning in videos, and now has plans to include them in future videos.

Eventual reduction in teaching workload

A flipped lecture can also lead to an eventual reduction in teaching workload. To be clear, this reduction is associated with lecture preparation time, by virtue of the flipped class – which replaced a traditional lecture – requiring little preparation since it was a homework help session. The videos and online quizzes of course require a substantial amount of time to develop; however, once developed, they can be "banked" and are easily deployed in future course offerings (i.e. a one-time time cost). For this fluid mechanics course, the videos were simple 3-to-10-minute PowerPoint voiceovers, which took approximately one hour longer to produce than the time needed to produce the PowerPoint slides themselves. Obviously an instructor can spend a large amount of time in video production depending on the desired quality of the video, but most campuses have resources and guidelines to help instructors efficiently create effective videos.

Focus on key learning objectives

A final instructor observation about flipping the class was that the weekly conversion of one traditional lecture to a flipped class forced a meaningful re-evaluation and streamlining of course learning objectives and content coverage, due to the loss of the lecture. While videos were utilized to offset this reduction, these videos were short, generally between 5-10 minutes (following best practices), and thus some content could not be covered in the course. This forced the instructor to prioritize certain more important course material over other content. The instructor was able to eliminate several "legacy" topics in the course that were in essence included because they had been included in past offerings, but many of these topics were too advanced and not well-suited to the majority of the students, the majority of whom would not take another course in fluid mechanics or hydraulics. Omitted topics included the "Buckingham Pi Theorem" and the "Reynolds Transport Theorem", much beloved topics among academic fluid mechanicians but topics that few, if any, of the students were likely to ever use after the course (or understand during the course!). The instructor essentially felt that the loss of the omitted topics was offset by the additional practice that the flipped class allowed on more meaningful topics.

Challenges to flipping the class

While most outcomes from flipping the class were positive, there were several challenges that the instructor encountered. Many of them centered on technology; flipping the class required the creation of online quizzes and videos. The online quizzes were created through the Blackboard Learn course software, and were comprised of multiple choice and formula-based questions. A significant amount of time was required to create and troubleshoot these quiz questions. The formula-based questions utilized randomized inputs (numbers) for each student, in an attempt to reduce cheating on the quizzes. Fortunately, the teaching assistant for the course did most of the quiz creation, but the instructor was aware that this would be a significant time expense if a teaching assistant was unavailable. The quiz questions can be re-used from one semester to the next, making their creation a one-time expense.

The time spent creating the videos for the course was significant, and time limitations precluded the creation of videos for all components of the course. Moreover, the videos were simple PowerPoint voice-over videos, and if an instructor wanted to make more elaborate videos, they would be even more time consuming. The videos are transferrable to future semesters, but it should be noted that they are much more difficult to modify than standard lecture materials (overheads, board notes, handouts). This lack of ability to easily edit videos would seem to support truly "bite size", modular videos that target lowest-level learning objectives for the course.

A non-technological challenge to flipping the class was the group work element for the flipped class. The instructor chose the simplest possible model for the flipped course (unstructured work on homework problems in self-formed groups) in part because that seemed to be the most manageable plan given a lack of experience with flipped courses. Some of the groups functioned well as teams, whereas other groups were simply disconnected students sitting near one another. Future semesters may involve a more formal group work component for the flipped class, but that will require additional work to determine strategies for forming student teams and assessing group work.

A final challenge that the instructor encountered in the flipped class was student cheating. This challenge is of course not unique to flipped classes, and the cheating encountered in the flipped class was not particularly different than what the instructor had encountered in previous (non-flipped) course offerings. The online quizzes were not proctored, and it is likely that some students did cheat on the quizzes. The instructor attempted to counteract this cheating by (1) having the quizzes worth only a small fraction of the students' grades (5-10%); and (2) warning the students several times that the quizzes were designed to be so easy as to render cheating as much work as actually doing the quizzes (this was especially true for the formula-based quiz questions). Homework cheating was treated in a similar manner – although students could easily copy solutions from their classmates, working with others was the point of the flipped class. Homework was also worth only a small amount of the students' grades, and students were frequently reminded that the best way to score well on the exams (which largely determined students' course grades) was to truly understand the homework. A final deterrent towards cheating on homework was the presence of the instructor and TA's during the flipped class, as well as the classmate and instructor/TA help offered during that session, which may have shown some students that they were in fact able to complete the homework without cheating.

While the instructor did find some elements of the flipped class semester challenging, on whole the instructor felt that the benefits associated with the flipped class outweighed these challenges and has decided to continue teaching in the flipped format.

Discussion

In this paper, we review the effects of transitioning a large fluid mechanics course from a traditional lecture-based course to a flipped course format. We were able to triangulate the effects of this flip by looking at student quantitative data, student comments about the course, and teacher observations in an effort to paint a more detailed picture regarding the effects of transitioning to a flipped course in a civil engineering class.

Regarding student performance, students in the final iteration of the flipped class (Spring 2015) performed better on the comprehensive final exam. We also found that flipped courses were associated with higher quiz average scores. It should be noted that because quizzes were due *before* the weekly work session, they were likely not a cause for the improved quiz performance in the Fall 2014 and Spring 2015 semesters. Rather, the increase was likely due to the availability of additional online videos that made it easier for students to comprehend the material (this explanation was also evidenced by student comments on the helpfulness of the online videos). Of course, the increase in online videos was an indirect effect of the flipped class because the format of the course necessitated that additional coverage of content be moved out of the classroom to accommodate the reduction of in-class time. Thus, the format of the flipped class in its entirety (both the work sessions and online course content) appear to have a positive influence on student performance in the class. While other recent case studies were unsuccessful in finding improvements in course performance following the transition to a flipped class,[21] it is promising to see these improvements in our data. There were no statistical differences found when turning to the other quantitative data (i.e., course and instructor rating and perceived learning gains), but it useful to know that flipping the course at the very least did not negatively affect student perceptions in these domains.

The data presented here suggest that flipping a course can lead to small improvements on quizzes and the final exam. This alone may not be a compelling enough reason to take the leap into redesigning one's course. Moreover, relying solely on quantitative data to assess the effectiveness of a flipped class can be misleading. Thus, it is useful to turn to other data elements to identify whether flipping a class is worth the effort.

The qualitative analysis of student comments about the course in general suggest that the features associated with a flipped class are making a positive difference. Students were not asked to provide comments on any specific element of the course, thus their feedback represents what they found to be the most salient aspects of the course. Overall, students frequently praised the work sessions, enjoyed collaborating with their peers and getting help from the instructor, and found the online videos useful. More specifically, students in the Fall 2013 traditional course had the option of attending a voluntary homework help session, which they found beneficial because they could work with other students in the class and could get help from the instructor. When this work session was built into the course (as opposed to being voluntary), more students commented on how much they enjoyed this feature, again stating that they were able to get help not only from the instructor but also their peers. Moreover, students in the flipped classes found

the online videos to be interesting and helped them better learn the material, resulting in improvements to quiz scores.

These results based on the analysis of student comments support previous literature. For example, having students solve problems rather than passively listening to how problems can be solved aids in improved comprehension.[4] Solving problems in a low-stakes environment also gives students an opportunity to demonstrate to themselves and others that they understand the material, thus enhancing their perceived competence, which is a crucial element in increasing student motivation and learning. In addition, being able to work more closely with peers and the instructor, which in turn enhances feelings of interpersonal connection, can have similar effects on motivation and learning.[22-24] When students have an opportunity to teach their peers about course content, they can increase the degree to which they understand the material themselves.[24] Finally, providing students videos to watch outside of class, as opposed to just textbook readings, can also lead to improvements in learning.[15-17] Taken together, student-identified elements of the flipped course that they found most helpful correspond well with strategies described in pedagogical literature that have been shown to improve learning.

Finally, the instructor's experience with flipping the course should not be under-valued. Through teacher observations, several additional benefits came to light that speak to the advantages of flipping a class. Increases in teaching satisfaction can arise by having more opportunities to interact with students where they can actually observe students engaging with and understanding the material. Through these interactions, instructors are better able to identify problematic conceptual areas, logistical issues that might arise due to instructor-error, and student characteristics that may suggest a preferred reliance on other learning techniques (e.g., realizing that non-native English speaking students may prefer written versus oral instruction). The work sessions also fostered improved peer-to-peer and peer-to-instructor relationships, which led to improvements in student comfort and engagement in the lecture. Furthermore, while initial efforts to create course content to be placed online (e.g., video lectures) may be time-consuming, this leads to eventual savings in time down the road. That is, once content has been created, it can be used in subsequent semesters without much additional effort. There is also a reduction in preparation time that stems from replacing one lecture per week with a work session. Finally, with the increase in active learning and the limited amount of in-class time to lecture, instructors are forced to hone in on key learning objectives that can most effectively be covered in the allotted time. In other words, they must identify and focus on the content that is most important for students to learn. Educational researchers have been emphasizing the need to shift from a focus on course depth rather than breadth;[26] turning to a flipped format course may help facilitate that shift. In sum, the instructor-perceived benefits to a flipped class far outweighed any initial challenges that were faced with the transformation.

Conclusion

With the emergence of flipped classrooms across the country, there is an associated emergence of scholarship assessing the impact of these redesigns. This paper adds to the body of knowledge on flipped classrooms by demonstrating that even the simplest approach to a flipped classroom (turning one lecture into an unstructured homework help session where students work in self-formed groups) is advantageous to students. It also provides additional empirical evidence that flipping a class can lead to student performance gains, a finding that has been

lacking in the engineering education literature. Finally, it provides a thorough description of instructor benefits to flipping a class, in essence answering the question for instructors, "Will it be worth my time to flip my class?". In the case of CE 300, flipping the class was not a flop, and additional benefits are expected to arise as the implementation of this redesigned course continues to improve over time.

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