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Call It What You Want: Blending Project-based Learning and the Flipped Classroom Model in a Civil Engineering Course

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Abstract

Both project-based learning and flipping the classroom have gained recent popularity in engineering education. These techniques change the classroom environment by placing the responsibility for learning on the students. Through a change in the traditional lecture model, students develop a higher investment in their work and have more agency in the learning process.

For this study, a senior level civil engineering class structured around the project-based learning format and focused on geotechnical foundation design was changed from a traditional lecture delivery format to a flipped classroom format. Blending of both instructional techniques resulted in a project driven flipped class, in which the students had the motivation provided by an open-ended design project mixed with the flexibility of a flipped class. The framework for this blended delivery as well as benefits and challenges from both pedagogical approaches identified in the literature are presented in this paper. The potential benefits of both approaches as well as student performance in the course were assessed. Although more research is needed in this field, the results of this study suggest that a blended approach can provide a more balanced educational experience by compensating the weakness of each approach with the benefits from the other.

Introduction

The traditional strategy for teaching engineering design bears many similarities to problem-based learning [1] which makes it attractive as a teaching framework for a design focused course. A subset of problem-based learning, project-based learning uses a long-term, ill-defined, and complex project to mimic real world conditions when teaching design to students. Advantages of project-based learning include stronger student motivation, students gaining a better understanding of how to apply their knowledge in practice, and improved teamwork and communication skills [1]. The benefits of project-based learning also include a democratization of the learning process; Frank et al [2] found that by using the project-based learning approach, teams that had started off the course being weaker made the greatest gain and were able to reduce the performance discrepancy with the stronger teams by the end of the course.

Flipped courses have been used in many parts of the Civil Engineering curriculum such as statics [3], mechanics of materials [4], [5], fluid mechanics [6], introduction to environmental engineering [4], and structural design of foundations [4], [7]. Adopting the flipped format allows for the implementation of pedagogical activities necessary to develop life-long learning skills [4] which are necessary for continued engineering practice post-graduation. It also allows for customization of the learning experience, as the flipped format asks students to take agency in how the classroom time is used. Problem-solving sessions, active discussions, and other active learning activities may happen in the classroom that would otherwise be replaced by content delivery. Students who are working on a long-term design project can use this active classroom time in order to acquire the skills they have identified as necessary to accomplish their project.

Engineering course projects, and especially the engineering capstone experience, are often experiences that revolve around group work in the service of a large and complex project. By blending the flipped classroom approach with a project-based learning approach, the goal is that the students will be better prepared for both the capstone experience and professional life post-graduation. The project-based learning component simulates professional practice by providing open ended design projects in which a range of possible solutions exist. Project based learning has been shown to increase student performance in a critical thinking test, as well as boosting student's self-confidence and learning ability [2]. The flipped model places primary responsibility for learning on the students, as they are able to greatly influence the content discussed and presented by the instructor. Results in this blended approach are relevant due to the lack of published research in using a flipped classroom in an upper-division engineering course [8], or of any blended approach to both a flipped classroom and project-based learning. This study is a starting point to begin reporting on the effectiveness of a blended approach.

Course description

The course used in this study, CER445 is a senior-level Civil Engineering class focused on the geotechnical aspects of foundation design. Topics covered include the analysis of geotechnical field testing data, the geotechnical design of various foundation types (shallow footings, mat foundations, piles, and drilled shafts), the structural design of shallow footings, and the geotechnical design of traditional retaining walls. The course meets 3 times a week for 50 minutes over a 13 week semester for a total of 39 class meetings.

The course is a required part of the curriculum for a new and small Civil Engineering program in a private university in the United States. Because of the small size of the program, all geotechnical courses (including the pre-requisite course to CER445 and all previous offerings of CER445) have been taught by the author. This allowed for an easier transition to the flipped model as the students were familiar with the instructor's teaching style and the formatting and style of class materials. The existing personal rapport with the instructor also provided for easier buy-in from the students into the flipped classroom model.

Prior to the flipped offering the course had been offered twice before for a total enrollment of 9 students (5 male, 4 female). The initial offering had an enrollment of 2 students, which increased to 7 students in the subsequent offering. These were delivered in the traditional format, with an instructor-centered presentation of the material through board notes on the chalkboard and Power Point presentations during class meetings. The material delivery was interspersed with breaks for discussion and clarification. Student performance was assessed through a semester-long project and several homework problem sets for the students to work on outside of class, as well as two partial examinations and one final examination. Because class meetings were used to deliver content, there were very few opportunities available to solve problems in class. For the traditional offerings only 5 class meetings (12.8 % of total face to face time for the course) had a significant problem-solving component. Students were expected to complete the homework problems and the design project on their own outside of class, making use of the instructor's office hours if they needed clarification on a subject.

The semester-long project was worth 20 % of the final grade and was assigned on the first day of class, with the final submission due on the day of the final examination. The project was designed to be a series of open-ended designed problems related to the course work. It has been present in each iteration of the course as a "design spine" to provide applications of the learned material as the course advances. For each topic presented in the course, the students complete a component of their project and submit it to the instructor for feedback. That partial submission is then graded, and feedback is provided on the design. The student is then able to make changes to their design, and each component is re-evaluated at the time of the final submission.

Active learning

Active learning is generally defined as "any instructional method that engages students in the learning process. In short, active learning requires students to do meaningful learning activities and think about what they are doing." [9] By participating in active learning, students engage in a deeper level of thinking and acquire the skills needed to be a life-long learner [4]. Prince [9] identifies problem-based learning as "an instructional method where relevant problems are introduced at the beginning of the instruction cycle and used to provide the context and motivation for the learning that follows". Flipping the classroom may also be considered an active learning technique [10] as it engages the students in their own learning during the problem-solving sessions in class meetings.

Project-based learning is the application of problem-based learning to a large, open-ended design project. Some of the benefits of project-based learning are enhanced student participation in the learning process, enhanced communication skills, and promotion of critical thinking [11]. A generally accepted benefit of problem-based learning is producing positive student attitudes towards the accomplishment of learning objectives; problem-based learning may also promote better study habits among students, increasing library use, textbook reading, class attendance, and studying for meaning instead of simple recall [9]. Project-based learning provides the same benefits, while also allowing the liberty for more open ended and complex problems to be presented to the students. Using project-based learning allows for the project to act as a "tentpole assignment", that is a central assignment which has components related to all the material studied in the class and that can give structure and organization to the material presented in the course while providing motivation to the students. As the students work on the same project, they engage in collaborative learning. In CER445 the students were different initial data which provided individual accountability. Students take a prominent role in directing their learning as they work on their project. They identify the knowledge needed to produce their designs, acquire it, and then apply it. Project-based learning provides opportunities to develop teamwork, problem-solving, and leadership skills [12], [13].

Additionally, the implementation of project-based learning increases the interaction time between the instructor and student [12] which results in more personalized learning. These one on one meetings between student and instructor can be highly effective in improving comprehension of the material for the student, as the instructor is able to tailor the clarifications and discussion of concepts to the student's preferred learning style. While this is a benefit in low enrollment courses, it can quickly become a drawback if enrollment sizes swell without an increase in teaching power dedicated to the course.

Flipping a classroom is generally understood to be the swapping of activities traditionally expected of the students inside and outside of the classroom. In a flipped classroom setting, the new content is presented asynchronously to the students, and they are expected to review it prior to attending class. This allows for the students to go at their own pace when absorbing new concepts. Classroom activities are then devoted to the practical application of the knowledge presented prior to class meeting. These principally consist of solving problems but may also include clarification of the material, class discussion, or other activities designed to enhance student learning [14]. Bishop [15] makes a strong case for the replacement of in person material delivery, which can be replaced without a loss in effectiveness by technological delivery of the content, and replacing it with problem-based learning which is a much more effective approach for meeting instructional objectives.

Flipping the classroom can lead to several benefits such as freeing class time for interactive activities like active and problem-based learning, presenting the educational material in different formats to cater to students' various learning styles and preferences, encouraging students to become self-learners, and preparing them for how they will need to learn as practicing engineers [8]. Engaging in the flipped format may also discourage breaches of academic integrity policies [6] as students' motivations to cheat are reduced. A flipped classroom may also better promote group activities and peer interaction, as well as offer extended open-ended problems to promoted development of creativity and innovation skills [7].

Though the potential benefits of delivering a class with the flipped approach are known, there is still some discussion on which group of students see the highest benefit. Laman [7] states that a classroom flip may improve the grades and content understanding of "students who are just below average and lower"; while Lee [5] finds that the flipped model has a greater positive impact on high and low achieving students. Mason [8] found that using a flipped classroom "at best improved the students' understanding of engineering concepts, and at worst did no harm" which was consistent with other studies.

Challenges when using the flipped method are present for the students as well as the instructor. Students can be reticent to move away from the traditional lecture format as it is familiar, comfortable, and it allows them to be passive participants because of the prominent role of the instructor in classroom activities [16]. This can be accompanied by a lack of motivation in the students [17]. Students also report struggling with effective time management, lack of social interaction with faculty and other students, and a lack of opportunity to ask questions [18]. Faculty may also have misgivings about switching to a flipped format. Adopting the flipped format represents an added work load on faculty due to the necessity of re-developing the course. A traditional lecture course likely requires less initial preparation and is also likely to be the mode of instruction most familiar to the faculty. A course re-design that incorporates the flipped model requires a large initial investment of time and effort to prepare the new classroom materials and for the instructor to familiarize themselves with this mode of instruction. However, that initial investment is offset by subsequent offerings of the flipped course requiring less faculty time [4], [8].

Transforming from traditional to flipped

The flipped modality of CER445 was first offered in the Spring 2018 semester, to a class of 6 Civil Engineering seniors (6 male, 0 females). The flipped class was designed closely following the "Approach 1" proposed by Swartz et al. (2001). This involves a prepared lecture, which augments the PowerPoint presentations used in the pre-flip offerings of the course with traditional board notes and occasional audio explanations added by the instructor. The tasks the students needed to accomplish before coming to class (reviewing the posted class materials such as board notes, PowerPoint presentations, and lesson guides) were designed to present the necessary detailed factual information to the student alleviating the need to present this material in class [7]. At the beginning of class time, a short review of the new information was done in a discussion format where the instructor gathered informal feedback from the students and cleared up misunderstandings or areas of confusion. This is a change from the original approach presented by Swartz which used a handwritten, self-graded quiz at the start of class to identify areas of weakness. The change was made to reduce the course load for the students (following one of the suggestions for a first-time flip from the authors to avoid adding assignments) and to allow for students who had not reviewed the material prior to class to fully participate in the discussion. After the necessary clarifications were discussed, the rest of class time was dedicated to preparing for the post-class application problems by outlining solutions for homework problems, solving problems analogous to the ones in the homework sets, and discussing design procedures and guidelines relevant to the project. Design alternatives for their projects were also discussed with the students. The designs were informally evaluated, and the students received feedback from the instructor on how to improve their designs. With few exceptions (two traditional lectures, two review sessions focused on material presented in the pre-requisite course, and 2 examinations which overall represented 15.4 % of class meetings) the flip was implemented throughout the entire course.

All use of the flipped time (33 periods of 50 minutes each, totaling 27.5 hours of face to face instruction) were designed around problem-based learning. These consisted of 27 Problem Solving days in which the class would work cooperatively to solve a problem chosen by the instructor. Any additional time after the necessary clarifications at the beginning of the period and the problem solving was used to outline homework problem solutions or discuss design alternatives, as requested by the students. The remaining 6 classes were Project Days, in which students were given time to work individually or in teams on their design project. It was encouraged that students bring a conceptual design to class so that they could focus on completing the technical with guidance from the instructor. This allowed for immediate feedback to be provided to the students, as well as in depth discussions about the students' design choices. These student-centered activities were carefully designed as they are integral to the success of the flipped model [15]. The distribution of class time use is shown in Figure 1.

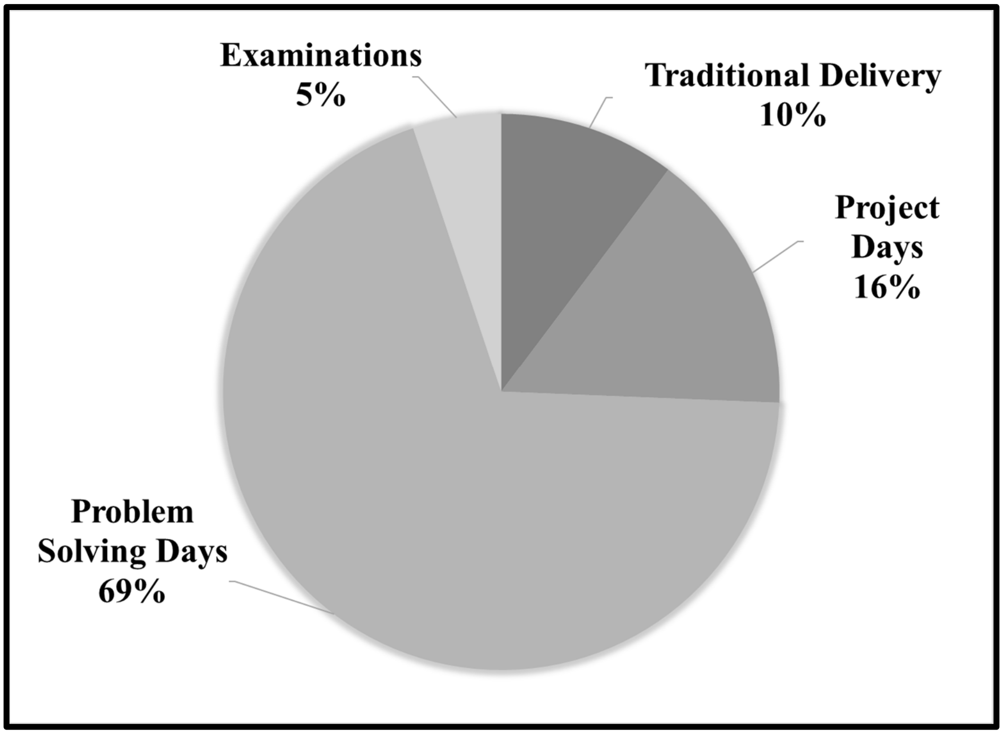

Figure 1 – Distribution of class time use in the flipped offering

The framework of project-based learning makes has an inherent synergy with the flipped. By combining both elements in one course, the benefits of each approach can accrue while softening the drawbacks. The project-based component of the course acts as a motivational and accountability tool as the students become invested in solving the presented design problems. It also transforms the student-teacher interactions into ones more focused on the students' needs [11] which can be addressed in class due to the extra classroom time allowed by the flipped format. The flipped format allows for the flexibility needed for the students to study the material necessary in a way that best fits them. Because of the asynchronous presentation of the material, they can review past lessons or scout ahead in the material to acquire the knowledge they need to work on their project. This also provides an added measure of organization to the course, as regular partial submission deadlines mean that the students must perform the out of class activities on schedule. The flipped modality also allows for detailed discussion of any material that the students have identified as necessary for completion of their project but isn't clear to them. In addition, flipping the classroom resulted in the availability of time which led to the creation of Project Days, in which the students would work on their project individually with the instructor present so that prompt feedback could be given on their designs. The extensive planning necessary to flip a classroom means that a detailed schedule of topics is typically available to the students at the outset of the course. That detailed schedule proves invaluable when students plan how to best work on the project. One drawback of problem-based learning is that students report spending more time working on the course [19] which increases the time requirements on an already crowded student schedule. However, this is offset by the use of the flipped format as students spend approximately 20 % less time outside of class on coursework, while maintaining or improving performance [5].

Results

Due to the small enrollment in this course (n = 6), the presented results should not be taken to imply wide applicability of the methods presented, but instead as a narrow sample of the application of these methods in a specific context. As the course is currently offered and should be offered in the spring semester for the foreseeable future, it is expected that more results from latter offerings will strengthen the data set.

Assessment of the flipped modality was done through 4 dimensions. These consisted of a mix of self-evaluations, plus grade comparisons to previous offerings of the course. Self-evaluations include the university wide course evaluation forms that all students complete for every course at Quinnipiac University, a self-assessment of achievement of Course Learning Outcomes, and a survey instrument specifically designed for the flipped offering to gather feedback on the students' experience. While the low sample size only allows for rough comparisons, the variety of assessments allows for a preliminary assessment of the students' performance and their attitudes towards blending the flipped approach with project-based learning.

Figure 2 presents the average scores for selected survey questions from the university wide class evaluation system. Unfortunately, the post-flipped offering only had a 66.67 % response rate to the university wide survey which reduced the sample size further. The survey asked students to evaluate different aspects of their course on a 5-point Likert scale. The figure presents both the pre-flip average responses for those questions (n= 9) and the post-flip average responses (n=4).

Some possible trends may be appreciated from the limited data set. First, it appears that switching to the flipped model resulted in an increase in student confidence of understanding the central concepts and ideas on the course. Students also are more slightly likely to believe that their critical thinking and problem-solving skills were enhanced during the flipped offering of CER445, as well as a slight increase in the student's belief that the course had been well organized. Additionally, there is a large increase in the students' perception of instructor-centered investment in the course's success, with a significant increase in students' assessment of the instructor's capacity to motivate the class and to use teaching techniques that actively engaged them in the learning process. This may due to the instructor discussing teaching methods much more explicitly in the flipped format than in the traditional format in order to get buy in from the students.

Especially interesting is the contrast between the increase in students' perception of a superior educational experience in the course with a decrease in their reported motivation (i.e. "As a student, I did my part to learn as much as possible in this course"). That loss in motivation is likely due to the change to a flipped format and is consistent with the existing literature on the flipped approach. The project-based learning component of the course is designed to provide extra student motivation and has been present since the course's inception. During the pre-flip offerings, the project seems to have increased student motivation, while adding the flipped component somewhat depressed student motivation. However, student motivation seems to remain high even post-flip. The author believes that this small loss in student motivation is offset by the gains in other areas of the course.

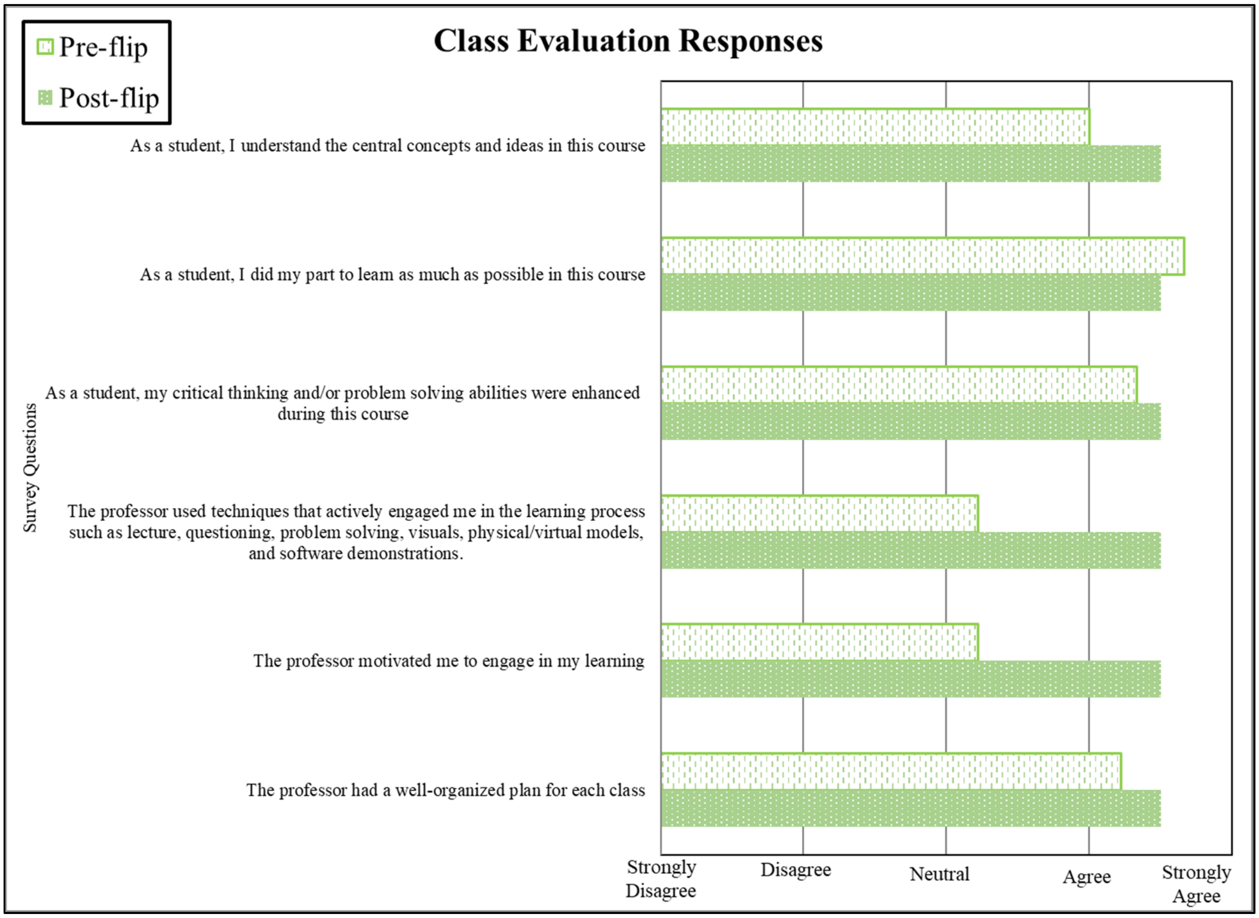

Figure 2 – Average pre and post flip responses to selected questions in the university wide course evaluation system.

Figure 3 shows the result of student's self-assessment of course learning outcomes attainment at the end of the course for both the pre-flip and post-flip offering. The students self-report their perceived attainment of every course learning objective using a 5-point Likert scale. The post-flip offering shows an increase in student confidence of attainment for every course learning outcome. The strongest increases were on the educational objectives related to design of geotechnical structures (CLOs 2, 4, and 5) and of design of a testing plan to acquire data (CLO 1). These course objectives were all the focus of "project days" where both design process and design philosophy were discussed by the entire class in the context of students' projects.

These results suggest increased student learning along all principal goals of this course. A stronger causal link between the new approach and increased student performance may be present, however due to the small sample sizes analyzed it is not able to be ascertained presently. If present, the author believes the link may be due to the addition of much more instruction time dedicated to both problem-solving and project design work that was added as part of the switch to the flipped model. As students were able to spend more time applying the skills they gained in this course to their design project under the instructor's guidance, it stands to reason that they would feel more accomplished in their design work at the end of the flipped offering.

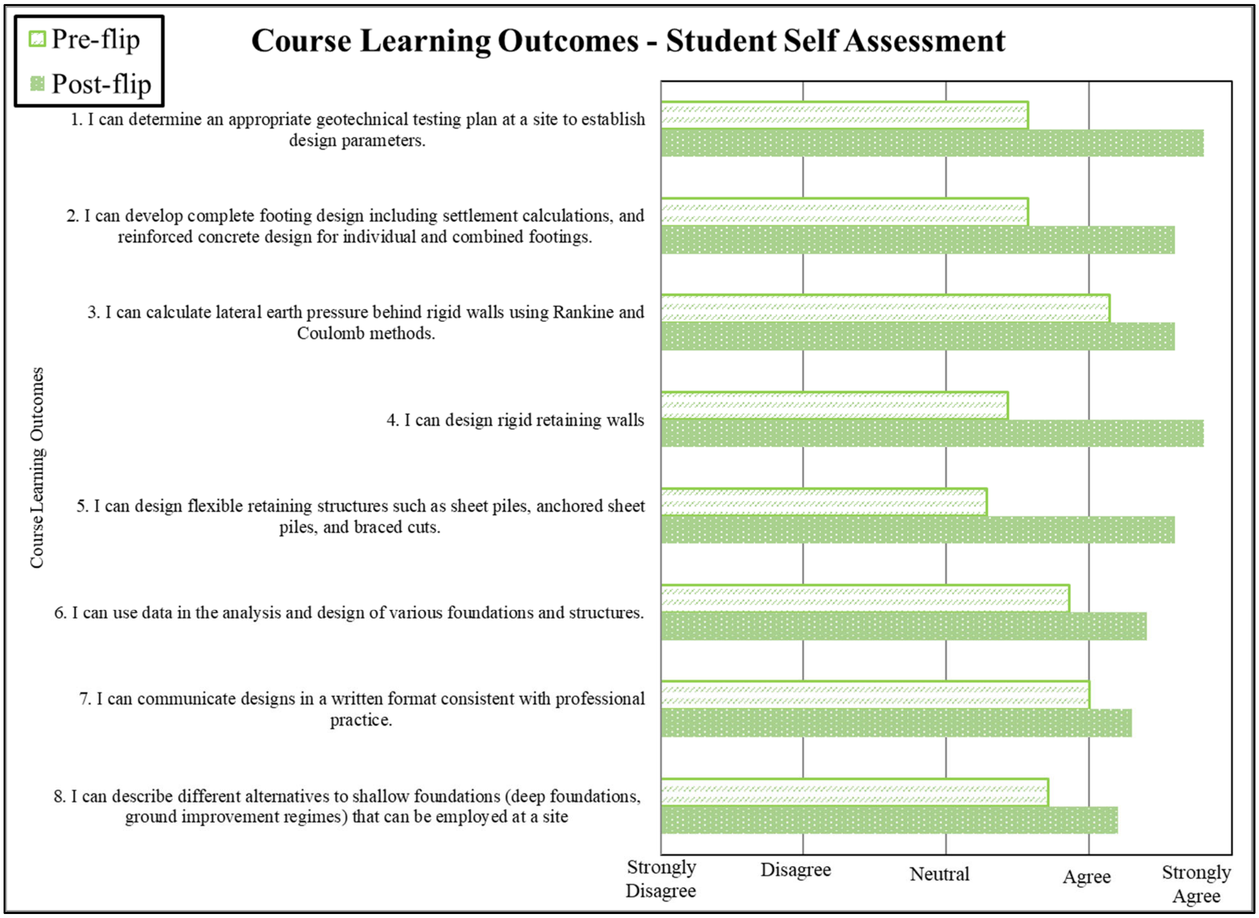

Figure 3 – Students' self-assessment of course learning outcome assessment for both the pre-flip and post-flip offerings

Overall, the students seem to have enjoyed the flipped classroom model on its own merits, although they struggled with the same challenges identified from the literature. The results of a flipped classroom satisfaction survey (n = 6) administered at the end of the semester are presented in Figure 4. The students were asked to express their disagreement or agreement with the statements presented using a 5-point Likert scale. These preliminary results show that students were not strongly in favor of the flipped model over the traditional model. However, the flipped approach received slightly positive assessments. The rapport developed with the instructor over previous courses may also impact the results, as the instructor-centered survey questions received the highest ratings on the survey.

As all three previous assessments are based on students' own perceptions, they are of limited usability for assessing the success of switching over to the flipped model. A direct assessment of student performance is also needed to provide an objective assessment of learning outcome achievement. Figure 5 shows the average grades pre and post flip for the combined homework grade, the project grade, the grades for both the partial examinations and the final examination, and the final course grade. While students' perceptions of learning improved with the flipped model, this increased confidence did not result in increased grades. Final grades for both the pre and post flip offerings are virtually equivalent. The average combined homework score had a slight increase with the flipped offering, which is likely due to the in-class work on homework problems that was implemented after the flip. While this is disappointing, the low sample size leaves open the possibility that an improvement in scores will be appreciated once more data is available. The decreased performance of the flipped classroom students in both the partial examinations also warrants continued grade monitoring as the data set grows. As the in-class problem-solving time is vastly increased in the flipped offering, it is expected that students taught using the flipped model would demonstrate an increase in examination scores. However, even if no improvement in performance was noted, Mason's [8] finding that switching to a flipped model would at worst maintain student performance is warranted.

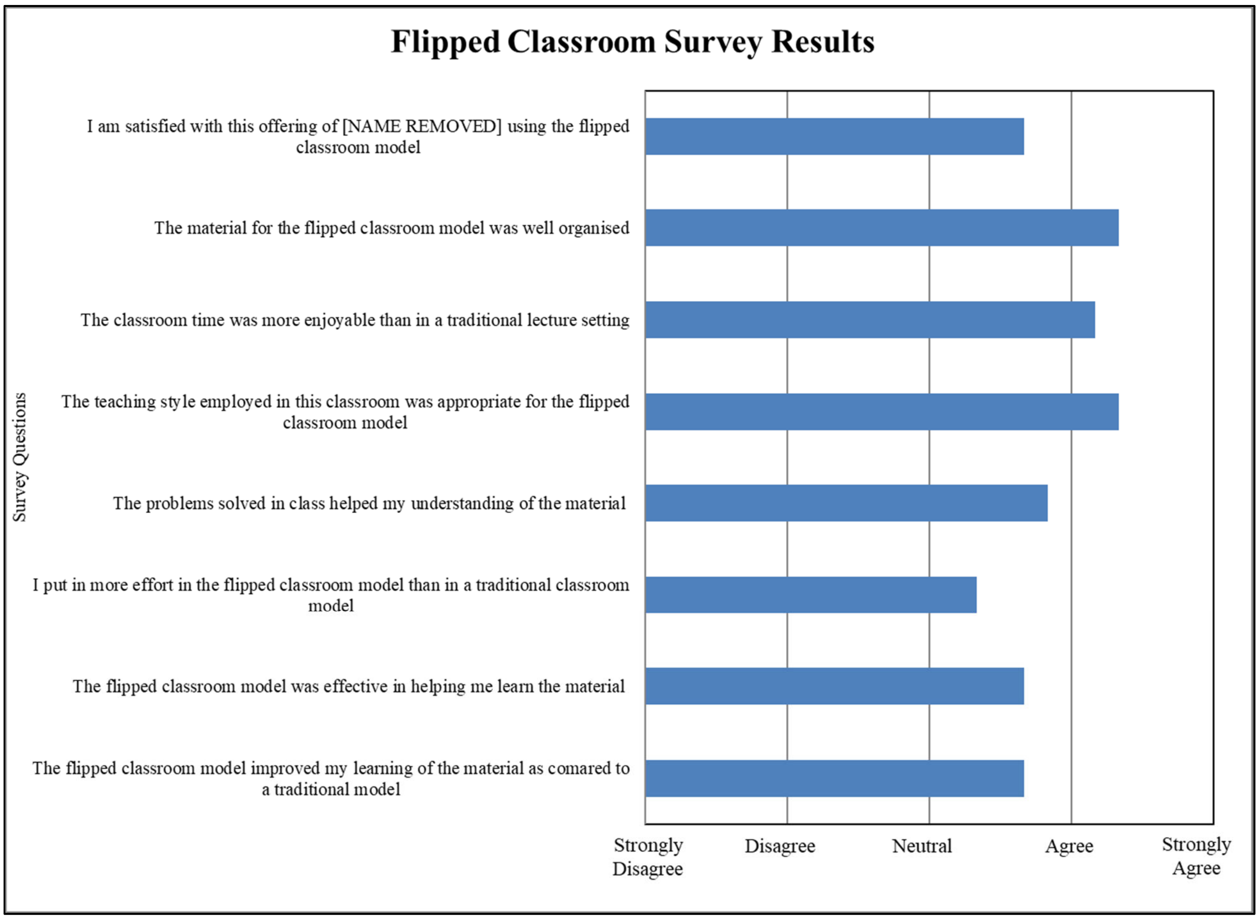

Figure 4 – Student responses to the flipped classroom satisfaction survey

Lastly, projects grades remained virtually unchanged between the traditional and flipped offerings. As the addition of project days was thought to help students perform better on their design project, the lack of increased project grades is unexpected. However, this may be due to a shifting of student-instructor interaction time regarding the project. Due to the low enrollment of the course, students had ample access to one on one time with the instructor during office hours prior to the adoption of the flipped format. This would indicate that the amount of time students spent in the in the project did not change after the flip and was instead just shifted to in-class time during project days, reducing the total student workload. Because time surveys were not conducted, only anecdotal evidence from the instructor is available to support this hypothesis.

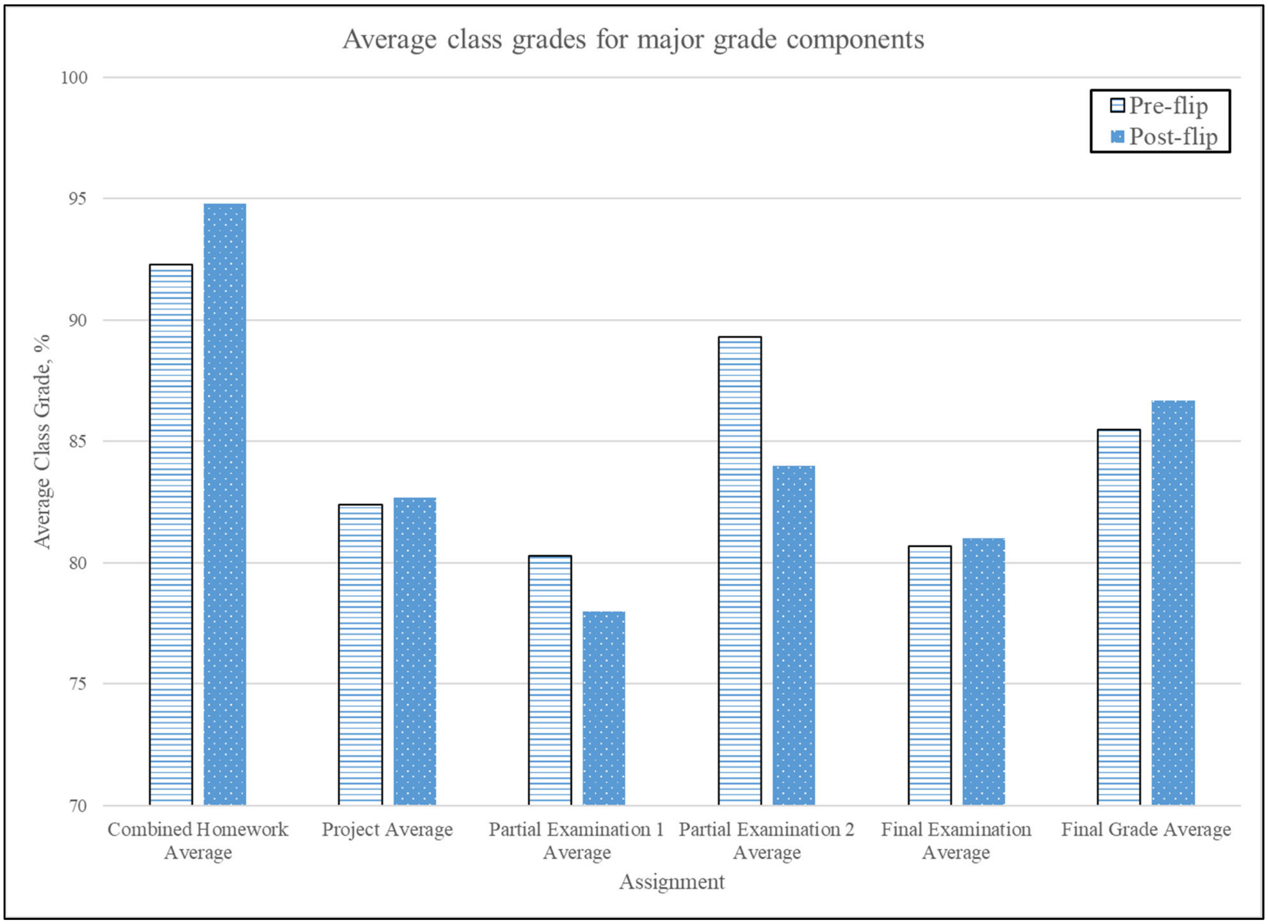

Figure 5 – Average class grades for major grade components in CER445

Discussion and current changes

Based on the limited data available, the flipped offering of CER445 which incorporated project-based learning) did not show any increase in student performance than the traditional approach using only project-based learning. However, survey results suggest that students' perception of both their educational experience and learning outcomes achievement showed improvement. Because of these results, it was decided to keep offering CER445 within the flipped format while incorporating incremental improvements to the flipped class. Student informal feedback, gathered through in person interactions with the instructor and written statements in class evaluations, showed a general appreciation for the project-based components of the course while only a slightly positive appraisal of the flipped model.

Both the initial design of the flipped offering of CER445 and any subsequent changes has been determined based on the literature available for the use of a flipped classroom in engineering. Table 1 compiles some of the salient benefits and challenges of a flipped classroom, along with the author's assessment of the presence of that benefit or challenge in their experience.

Table 1 – Benefits and challenges of a flipped classroom and the author's assessment of those benefits and challenges.

Benefits	**Author's Assessment**
Students are prepared for class	This had mixed results. A slight majority of the students came better prepared to classes than in previous courses where they had been taught by the instructor. The rest of the students did not consistently do the out of class work, though this was consistent with the instructor's experience with those students.
Faculty can use class time to discuss applications and deeper level thinking instead of mundane topic	This was one of the principal improvements to the class. Class time was much more engaging, and problem-solving days as well as project days were well received by the students.
Faculty can use class time for any number of activitis without worrying about covering content	Content coverage was improved from previous offerings. While the amount of material covered remained unchanged pre and post flip, the material was able to be discussed in much more depth in class.
Class can be better organized without concern about not covering enough material in class	A slight increase in students' perception of class organization was noticed. The instructor agrees with this finding based on anecdotal evidence.
Learning becomes student-centered, not instructor centered	This was another principal improvement to the class in the flipped offering. However, students were not quick to adapt to the new student-centered approach and needed an adjustment period.
Challenges	**Author's Assessment**
There is an initial investment of time for faculty to create out of class material	As the change to the flipped format necessitates both the creation if updated class materials and a change in teaching style, the initial investment of time can be quite onerous. However, it is comparable to the development of a traditionally delivered course and is offset by reduced preparation time for future offerings
The class must be well organised and carefully mapped out	Traditional lecture based classes may be taught without extensive advance preparation, which cannot be done with the flipped format. For this reason, the author recommends only flipping classes that the instructor is familiar with already. Previous offerings of a course will ensure that the necessary organization and preparation can be used to reduce faculty workload when flipping.
It is often difficult to re-create the out of class material	Previous offerings of a course by the instructor will reduce the difficulty of re-creating educational materials. As the author had two previous course offerings, the re-creation of out of class material only presented time management challenges as it added to their workload.
Faculty may struggle with letting go	This may be component of flipping the classroom that faculty struggles the most with. As many instructors will be unfamiliar with the flipped format, faculty may experience anxiety "buying in" to the flipped model as much as the students. This can be alleviated to some extent by phasing the flipped format as the course advances (see Laman's experience in [4]). However, once the change has been committed, faculty may wih to adopt it wholecloth so as to maintain consistency throughout the course.

Student feedback and instructor observations were also used as basis for incremental improvement to the course. The current offering of CER445 has incorporated these changes in hopes to improve both the student experience and performance. In the current offering of this class all lessons are delivered with the flipped framework, which only leaves the two class periods dedicated to partial examinations as non-flipped deliveries. Based on recommendations from both the literature and students, short lectures (10-15 minutes) have been recorded for the students. The lectures are recorded using Microsoft PowerPoint and the built-in microphone for the author's laptop computer, so no specialized equipment is needed. This also helped maintain some stability in the students as no new software was used, and instead a new element was added to an existing feature of their previous course.

Due to the asynchronous nature of content delivery, it is crucial that students are engaged in the classroom in order to maintain classroom attendance [20]. Engagement was maintained by using active learning techniques such as think-pair-share and questioning. An added incentive to maintain attendance were the in-class problem solving sessions which have an increased focus on homework problem sets assigned to the students. This allows for the opportunity to increase homework scores by securing one correct problem, typically worth 15 to 20% of the problem set. The impact of substituting traditional lectures (comprising a mix of PowerPoint slides, board notes, and in-person discussion and explanations) for captured lectured (which fold the board notes and explanations into the slides while leaving the discussions for classroom time) is largely unknown [18], and will be assessed for this course once data becomes available.

Conclusions

A blended approach combining the flipped instruction model with project-based learning was implemented in a senior level geotechnical engineering course. The flipped course was redesigned to closely follow an approach detailed in the literature [4], which had identified several benefits and challenges to implementing the flipped approach in an engineering course. Because of the low enrollment in the course, the data set relies on a small student sample. Thus, conclusions drawn from this study should be evaluated accordingly and used to direct further research and not to draw broad generalizations.

The flipped classroom approach detailed in this study was generally well received by students enrolled in CER445, with a majority voting to keep the approach in future offerings. This agrees with the values found in the literature; for instance with the 71.4 % of students (n=21) voting in favour of maintaining the flipped model in a mid-semester survey of a Mechanics of Materials course [4]. However, students who were not in favour of maintaining this framework spoke strongly against it with their primary concern being a perception that the flipped approach was more demanding on their time. This concern is not uncommon among students and has been reported before in the literature [4]. Another student concern was time management. While they were able to appreciate the benefits of flipping the classroom, they felt that due to their developing time management skills they were unable to do the pre-class activities consistently. As the students stressed this was due to planning issues on their part and not on an excessive out of class load, the author recommends discussing course expectations at the beginning of the course to ensure that students participate in all pedagogical activities, both inside and outside of the classroom. This issue has also been addressed by using a mantra about the necessity of students actively participating in the classroom which has been reported to be used in the literature [4]. The author has introduced this mantra to the current offering of the class and hopes that it will prove effective.

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