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Flipped Classroom as Blended Learning in a Fluid Mechanics Course in Engineering Technology

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Dr. Ayala received his BS in Mechanical Engineering with honors (Cum Laude) from Universidad de Oriente (Venezuela) in 1995, MS in Mechanical Engineering in 2001 and PhD in Mechanical Engineering in 2005, both from University of Delaware (USA). Dr. Ayala is currently serving as Assistant Professor of Mechanical Engineering Technology Department, Frank Batten College of Engineering and Technology, Old Dominion University, Norfolk, VA.

Prior to joining ODU in 2013, Dr. Ayala spent three years as a Postdoctoral Researcher at University of Delaware where he expanded his knowledge on simulation of multiphase flows while acquiring skills in high performance parallel computing and scientific computation. Before that, Dr. Ayala hold a faculty position at Universidad de Oriente at Mechanical Engineering Department where he taught and developed graduate and undergraduate courses for a number of subjects such as Fluid Mechanics, Heat Transfer, Thermodynamics, Multiphase Flows, Fluid Mechanics and Hydraulic Machinery, as well as Mechanical Engineering Laboratory courses.

In addition, Dr. Ayala has had the opportunity to work for a number of engineering consulting companies, which have given him an important perspective and exposure to industry. He has been directly involved in at least 20 different engineering projects related to a wide range of industries from petroleum and natural gas industry to brewing and newspaper industries. Dr. Ayala has provided service to professional organizations such as ASME. Since 2008 he has been a member of the Committee of Spanish Translation of ASME Codes and the ASME Subcommittee on Piping and Pipelines in Spanish. Under both memberships the following Codes have been translated: ASME B31.3, ASME B31.8S, ASME B31Q and ASME BPV Sections I.

While maintaining his industrial work active, his research activities have also been very active; Dr. Ayala has published 90 journal and peer-reviewed conference papers. His work has been presented in several international forums in Austria, USA, Venezuela, Japan, France, Mexico, and Argentina. Dr. Ayala has an average citation per year of all his published work of 33.25.

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Dr. Otilia Popescu received the Engineering Diploma and M.S. degree from the Polytechnic Institute of Bucharest, Romania, and the PhD degree from Rutgers University, all in Electrical and Computer Engineering. Her research interests are in the general areas of communication systems, control theory, and signal processing. She is currently an Assistant Professor in the Department of Engineering Technology, Old Dominion University in Norfolk, Virginia. In the past she has worked for the University of Texas at Dallas, University of Texas at San Antonio, Rutgers University, and Politehnica University of Bucharest. She is a senior member of the IEEE, serves as associate editor for IEEE Communication Letters, and has served in the technical program committee for the IEEE ICC, WCNC, RWW, VTC, GLOBECOM, and CAMAD conferences.

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Dr. Vukica Jovanovic is an Assistant Professor of Engineering Technology in Mechanical Engineering Technology Program. She holds a Ph.D. from Purdue University in Mechanical Engineering Technology, focus on Digital Manufacturing. Her research is focused on mechatronics, digital manufacturing, digital thread, cyber physical systems, broadening participation, and engineering education. She is a Co-Director of Mechatronics and Digital Manufacturing Lab at ODU and a lead of Area of Specialization Mechatronics Systems Design. She worked as a Visiting Researcher at Commonwealth Center for Advanced Manufacturing in Disputanta, VA on projects focusing on digital thread and cyber security of manufacturing systems. She has funded research in broadening participation efforts of underrepresented students in STEM funded by Office of Naval Research, focusing on mechatronic pathways. She is part

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Flipped Classroom as Blended Learning in a Fluid Mechanics Course in Engineering Technology

Abstract

Flipped classroom has gained attention in recent years as a teaching method in which the time allocated for introducing new concepts and the time used for practicing them are inverted, in order to provide more time for problem based learning and class interaction under direct supervision of the instructor. The implementation of this teaching method is comprised of two main components, the pre-class activities, which consist of individual student work and are largely based on pre-recorded videos, and in-class activities, which are group activities supervised by the instructor. This paper discusses the implementation of the flipped classroom method in a Fluid Mechanics course in an Engineering Technology program at a midsize university. The study presented was conducted over four consecutive semesters, the data representing four different groups of students. In the study presented, an important percentage of the students took the course in an online setting, either synchronous or asynchronous mode, which created an atypical situation compared to other implementations of flipped classroom method presented in the literature. It was found that the length or the format of the pre-recorded videos were not critical factors in determining the students to review them before the class. The unconventional setting of the class, including both in class and online students, required originality in handling the in-class activities. The best approach was to delegate students to lead the group discussions associated with solving the problems, while the instructor acted as an observer when the discussions were constructive and as a guide when the solution was getting out of rail or when the students were struggling. A survey was distributed to the students at the end of the course as a post-class activity, concluding the implementation considered in the study. The results of the survey showed that the students were satisfied with the teaching method and found it important in their learning process.

Introduction

Flipped classroom is a strategy of blended learning that recently gained attention in various engineering education communities. This method was originally developed for enhancing student learning by flipping the traditional lecture with enhanced online and video learning. This process allows students to access basic content and lectures via technology, through computers, tablets, smartphones, and other devices, outside of regular class time. This way, the instructors are able to reserve more class time for interactions with the students, and to devote most of the class time to problem solving and to answering questions germane to the materials students covered outside of the classroom [1].

The use of flipped classroom method in engineering courses seems to match perfectly the need of learning by solving real-world problems for engineering students [2]. "Engineering lends itself" to this new pedagogical approach [3], since traditionally it relies considerably on hands-on experiments and projects, as higher levels of learning. A study done for a first year digital circuits course [4] showed improved effectiveness of the flipped course compared with traditional course, in terms of course content, student performance, and students' perception of their learning experience. The National Research Council also identified in 2011 that providing feedback during application activities, like problem solving, is a critical component of education, making flipped classroom a good approach to accomplish that [5].

There have been several implementations of flipped classroom method in engineering courses, with focus on civil, electrical, industrial, digital, and software engineering; materials science, statics, MATLAB, and mechanics of materials, and detailed analysis of these studies are available [1], including details of the implementations and of the evaluation process. Other implementations of the flipped classroom technique were applied in courses of: introduction to engineering [3], chemical and thermal processes [6], differential equations [6], electromagnetics [7], electric drivers [8], digital circuits [4], calculus [9], civil engineering systems [10], and heat transfer [11]. Most of the flipped classroom studies targeted lower level undergraduate classes, which are core courses in all engineering majors and, interestingly, very few implementations have been done in upper level engineering courses, particularly in mechanical engineering courses. To the best of the authors' knowledge, no studies related to Fluid Mechanics are available.

Fluid Mechanics has been traditionally one of the hardest courses for any Mechanical Engineering student. The main reason is that the topics are entirely new to them, it relies on mathematical background, and there are substantial differences among the types of problems encountered in the class, as different techniques and mathematical approaches are needed for different parts of the course. Flipped classroom technique seems to offer the opportunity to increase the number of practice problems solved during lecture classes. In this study, the flipped classroom technique has been implemented during four consecutive semesters in a Fluid Mechanics Class in an Engineering Technology Department. Lectures were recorded with the assistance of staff from the Center of Learning Technologies. The students were asked to watch recorded lecture modules before the class time and classroom time was used for problem solving, discussions and Q/A sessions related to the material. Particular to this implementation was that the course was offered in a hybrid setting, with both traditional face-to-face groups and online groups (including synchronous and asynchronous attending students), which required special consideration to the in-class activities. Most of the studies on flipped classroom have focused on in-class activities with small-groups [12], which is not possible in a hybrid-teaching mode (face-to-face and online). Very few papers for engineering courses have described in detailed how the in-class activities were implemented [7, 8, 4], but they all considered only the traditional face-to-face teaching mode.

The main objective of this study was to evaluate the effectiveness of the flipped classroom method on student's learning in mathematical intensive classes and in a hybrid (traditional & online) teaching setting.

The Class Setting

The Fluid Mechanics course in the Mechanical Engineering Technology program at this midsize university is a 3 credits 300-level course. The class meets twice a week for 75 minutes each time. More than 80% of the students are already in their senior year when registering for this class.

The course has been structured in 4 main modules: static of fluids, dynamics of fluids, specialized topics on fluids, and turbomachinery. Traditionally a fluid mechanics course is a challenging one due to its heavy mathematical content. In this study, as the course is part of a technology program, the course curriculum is concentrated on the use of the major concepts in industrial applications, therefore the problem solving and project design are central to the teaching approach of this class. For example, the module on dynamics of fluids, which focuses on fluid flow in pipes, has been historically the most challenging one for the students. The instructor's experience and the feedback from students were jointly pointing towards the need of more problem solving in the class to assist with the students' struggle with some concepts. The flipped classroom teaching method emerged as a solution, especially for modules as the one mentioned above, since instead of leaving the students to struggle on their own with homework problems they could spend more time to practice problems directly assisted by the instructor.

At this midsize university there are other aspects that have serious impact on student performance in a challenging course such as Fluid Mechanics. There is a wide diversity among student body, including traditional students, students in different age groups with a large group of students returning to school after a long break period, full-time workers, active military students, veterans, students of underrepresented groups, and transfer students from community colleges. This diversity creates a non-coherent group of students in the class, with different study habits, background levels and needs that adds to the difficulty of the subject, and makes the teaching of the class very demanding. Another impediment is that the Engineering Technology major math requirements are significantly lower compared to the long-established Engineering majors, and some concepts can only be explained in a holistic way without relying on the mathematical proofs. In this case the problem solving and practical applications should balance the mathematical rigor. But the most challenging aspect of teaching this course came from the hybrid setting of combined in-class and online attending students. For the online mode, students can choose to attend either synchronously or asynchronously, since the class lectures are recorded and archived. The number of online students varies; it is about 30% to 50% during spring semesters, in contrast to 65% to 70% during fall semesters. Some of the online students are on-campus students that preferred the online mode. The availability of the recorded lectures affects the class attendance with the actual number of students in the class (both face-to-face and online synchronous) varying a lot from lecture to lecture, from about 50% to 100%. All of these combined challenges required a fine tuning of the teaching approach of this fluid mechanics course, and flipped classroom emerged as a viable solution to accommodate the non-homogenous group of students in their learning process.

The Flipped Classroom Implementation

The Flipped Classroom was implemented during the following 4 semesters: Spring 2015, Fall 2015, Spring 2016, and Fall 2016. The activities incorporated with the flipped classroom implementation were scaffolded as follows:

Pre-class Activities

During Fall 2014, the instructor`s videos were recorded during live lectures. This semester the class was taught in traditional way but the videos recorded served as the backbone of this flipped classroom implementation. They contained the lectures in which the concepts were introduced as well as the solutions to some sample problems, but they also contained the class discussions recorded live during the Fall 2014 class. Nevertheless, during the subsequent semesters, when the flipped classroom approach was implemented, the students were asked to watch the recorded lectures before coming to the class. Throughout the 4 semesters considered in this study the instructor made syllabus changes to ensure that the students are watching the recorded lectures as required. Some of the strategies implemented each semester were as follows:

SPRING 2015: Not the whole course was taught using flipped classroom technique. There were a total of five flipped classes during the whole semester and their topics were on series pipelines, parallel pipelines, and pipe networks. The students were asked to take a short quiz after watching each prerecorded lecture.

FALL 2015: During this semester only 3 lectures were flipped, and the concepts covered by these lectures were parallel pipelines, and pipe networks. The students were asked to take a screenshot of the video they were watching at some specific moments, as part of a graded homework assignment. Another assignment that was experimented was to require the students to work ahead on the problems that were proposed to be solved with the whole group of students at the subsequent flipped class meeting, with the idea that students would come to the class better prepared for discussions, and with more questions for the instructor. This initiative was not well received by the students, as they complained of insufficient time ahead of the class to study the lectures and to work on the problems.

SPRING & FALL 2016: With some lessons learned from the previous semesters, the flipped classroom technique was applied to one of the first lectures of the semester, on a topic that the students handled well in previous semesters (buoyancy) using traditional classroom. This first flipped lecture served as training for the students, for them to become conscious of the need to watch the recordings before coming to the class. For these implementations of the course, the students were asked as graded homework assignment to take notes while watching the videos and submit those notes along with a reflection paragraph about what was learned from the lecture. They were also informed that the Blackboard tracking feature was activated to keep track of whether they actually watched the video or not.

In-class Activities

Different strategies were used for in-class activities also, and the variations among the four semesters were as follows:

SPRING & FALL 2015: A critical problem in implementing the flipped classroom technique during these semesters was due to a large percentage of asynchronous online students. These were students registered online who were watching the recordings after the class was delivered and they were not virtually participating to the class discussions. The whole idea of bringing the students together and let them take the lead in solving problems, their presence being either in person or virtual, could not be applied, since a large group of students were not participating to the meetings. These students would only be able to watch the discussions of the participating students at a later time. Due to this problem, even though the in-class activities were focused on problem solving and not on introducing new concepts, the presentation was led by the instructor while the students (face-to-face or synchronous-online) only participated to the discussions in a manner similar to the traditionally taught class. With this approach, the benefit of the flipped classroom method resided in the extra class time for problem solving, but the instructor was still the one to initiate the solutions and the students were only passive participants to the learning process.

SPRING & FALL 2016: Again the experience of the previous semesters paid off. The instructor was able to convince a couple of students to take the lead in solving the problems while the rest of the present students (face-to-face or synchronous-online) actively engaged in discussing the solution. This became a success as the students were stimulated to come up with ideas and to debate them. The student leader was initiating ideas for the solution, was directing the discussions and was also recording the solution as the discussions were progressing. The solutions were formulated step by step but the final numerical calculations were not carried out. The class became engaged in an active learning process. The student leader would struggle or make errors during the process, and the rest of the class would debate and eventually correct those errors, but learning to correct the errors is a very important aspect of learning. Even for the asynchronous students that did not actively participated and were only watching the recordings of the problem solving process, the lessons were very beneficial. The recordings were more engaging than a regular lecture, and the analysis of different ideas that turned out to be either correct or wrong were very important for the learning process. In this set-up the instructor only intervened with guiding questions when: 1) the students were getting stuck or, 2) when the instructor noticed the procedure was going in the wrong direction. The instructor also asked questions on hypothetical cases related to the problem at hand after all students were clear on how to handle it.

Post-class Activities

During the semesters of Spring 2015 and Fall 2015 the students were not asked for any post-class activity, since the problems were fully solved by the instructor. For the Spring 2016 and Fall 2016 semesters, when students were leading the problem solving process, formal solutions of the problems discussed, including complete numerical calculations, were required as post-class homework assignments. Students were asked to complete these assignments individually. Reviewing the problem solving process and presenting a complete and rigorous solution were reinforcing the lessons learned completing the learning process.

The Survey Description

In order to evaluate the student perception on the flipped classroom technique, an anonymous survey was distributed to the students towards the end of the semester. The survey was posted in Blackboard and the students were reminded that the survey was anonymous and that their feedback is very important for improving the teaching method. The lowest participation rate was 76.92% in Spring 2015. The total number of students in each semester was: 34, 62, 47, and 56 for Spring 2015, Fall 2015, Spring 2016, and Fall 2016 respectively. The survey was a variant of the surveys used to study the impact Personal Responses Systems implementation in classrooms, such as for clikers [13] and Polleverywhere online system [14]. There were few initial demographical questions that were not used in this study. There were two general questions: 1) how often did they watch the pre-recorded lectures? With the options being: Never, Sometimes, Most of the time, or Always, and 2) what is your overall GPA? With the options being: between 4.0 and 3.5, between 3.5 and 3.0, between 3.0 and 2.5, or Below 2.0. Then, the survey included 15 questions with possible answers rated with 1 to 5 points from strongly disagree to strongly agree. Table 1 shows all those 15 questions. In Fall 2016 an open-end question was also included asking students for suggestions for improvement based on their experience.

Table 1. Summary of the survey questions.

Q1	Class time passes more quickly in a flipped classroom format
Q2	When in a flipped classroom format my participation increases
Q3	Using flipped classroom format during class did not help me in my learning
Q4	Learning with flipped classroom format improves my understanding of the course content
Q5	Using flipped classroom format encourages me to spend more time preparing for class
Q6	Learning with flipped classroom format gives me confidence to ask more questions
Q7	Using flipped classroom format encourages me to attend more classes
Q8	Using flipped classroom format promotes more focused discussions during the class
Q9	I would like to use flipped classroom format in other courses
Q10	Using flipped classroom format in class is too time consuming
Q11	I do better in my class without flipped classroom format
Q12	I would have liked to use flipped classroom format more often in class
Q13	Using flipped classroom format helped me better prepare for quizzes and tests
Q14	Using flipped classroom format helped me understand the concepts
Q15	Using flipped classroom format helped me learn how to apply the concepts to practice

The Surveys' Results

Survey on Student Perspective

With respect to whether the students watched or not the videos, Table 2 shows the percentage of students who always, most of time, sometimes, or never watched the recorded video lectures. The answers show that there is always about one quarter of the students who do not watch the videos an appropriate number of times. However about 75% of the students do watch the videos before the in-class activities, which proves that they understood their responsibilities. The lowest percentage of students watching most of the videos or all was during Fall 2015 when the students were asked to also work on problems before the in-class activity. This requirement was expected to make the in-class activities more efficient but impacted negatively students' time management out of the class. The highest percentage of students watching most or all of the videos was during Fall 2016, when the students were asked to turn in their lecture notes and the tracking feature was activated in Blackboard. Students were motivated to watch the videos since failing to do so would result in points deducted from homework grades. The format or length of the videos were not affecting the results since the videos were mandatory, and mechanisms of control were put in place through graded assignments. Similar findings and percentages of students watching most of the videos were observed in previous studies [1].

Table 2. Answers to the question: *How often did you watch the pre-recorded lectures?*

How often did you watch the pre-recorded lectures?	Spring 2015	Fall 2015	Spring 2016	Fall 2016
Always	50%	33%	36%	48%
Most of the time	25%	32%	36%	28%
Sometimes	25%	35%	25%	22%
Never	0%	0%	3%	2%

To analyze the data of the 15 likert questionnaire the "strongly agree" and "agree" answers were compile as positive answers and similarly the "strongly disagree" and "disagree" as negative answers, such that students' answers were aggregated in three categories, positive, undecided, and negative answers, as shown in Table 3. Note that negative answers in questions 3, 10, and 11 have positive meaning so their "strongly disagree" and "disagree" answers were counted as positive answers in Table 3, and "strongly agree" and "agree" as negative answers. The data summary in Table 3 was color coded such that the highest percentages were highlighted. If two different answers had the same percentage, they were both highlighted.

The results summarized in Table 3 show that the most divided answers were for the Spring 2015, with no clear pattern to be established. It was the semester in which most of the outside student work was required and the data show the negative impact this requirement had on the whole experiment implementation. As the experiment progressed and experience was accumulated the trend was for increased rates of positive answers, showing improvement in the implementation of the flipped classroom technique for the fluid mechanics course. The data for Fall 2016 show the most positive answers, especially for questions 3 and 14, which are related to the relationship between the flipped classroom teaching method and student learning.

The questions in the survey targeted different aspects of students' opinion and an analysis of the question set is presented next. Questions Q1 (Class time passes more quickly in a flipped classroom format) and Q10 (Using flipped classroom format in class is NOT too time consuming) addressed the students' opinion on classroom format and especially the answers for Q1 show an increasing positive trend.

Table 3. Summary of the positive (👍), undecided (😕), and negative (👎) answers over the four semesters implementation.

	Questions	Spring 2015			Fall 2015			Spring 2016			Fall 2016		
		👍	😕	👎	👍	😕	👎	👍	😕	👎	👍	😕	👎
1	Class time passes more quickly in a flipped classroom format	15%	40%	45%	33%	29%	37%	18%	39%	42%	46%	26%	28%
2	When in a flipped classroom format my participation increases	15%	35%	50%	28%	37%	35%	33%	33%	33%	26%	30%	43%
3	Using flipped classroom format during class DID help me in my learning	45%	15%	40%	53%	18%	26%	45%	24%	30%	70%	15%	15%
4	Learning with flipped classroom format improves my understanding of the course content	35%	35%	30%	47%	33%	20%	45%	30%	24%	67%	17%	15%
5	Using flipped classroom format encourages me to spend more time preparing for class	60%	10%	30%	47%	20%	45%	61%	21%	18%	67%	13%	20%
6	Learning with flipped classroom format gives me confidence to ask more questions	30%	35%	35%	35%	31%	33%	36%	27%	36%	52%	26%	22%
7	Using flipped classroom format encourages me to attend more classes	30%	25%	45%	29%	33%	37%	27%	36%	36%	39%	28%	33%
8	Using flipped classroom format promotes more focused discussions during the class	55%	25%	20%	47%	31%	22%	52%	27%	21%	63%	15%	22%
9	I would like to use flipped classroom format in other courses	40%	15%	45%	39%	22%	40%	36%	30%	33%	50%	22%	28%
10	Using flipped classroom format in class is NOT too time consuming	40%	25%	35%	33%	33%	34%	30%	33%	36%	50%	20%	30%
11	I do better in my class WITH flipped classroom format	15%	35%	50%	27%	39%	33%	33%	42%	24%	63%	20%	17%
12	I would have liked to use flipped classroom format more often in class	10%	35%	55%	26%	37%	33%	27%	24%	48%	35%	30%	35%
13	Using flipped classroom format helped me better prepare for quizzes and tests	35%	30%	35%	35%	35%	29%	48%	27%	24%	52%	24%	24%
14	Using flipped classroom format helped me understand the concepts	40%	20%	40%	59%	27%	14%	42%	33%	24%	70%	11%	20%
15	Using flipped classroom format helped me learn how to apply the concepts to practice	70%	10%	20%	55%	27%	18%	67%	21%	12%	59%	20%	22%

A set of questions (Q3, Q4, Q11, Q13, Q14, and Q15) addressed the students' opinion on whether the flipped classroom helped them with the academic content. The color codes show that the majority of the students think that flipped classroom helps with the academic content. The average percentage of positive answers started in 40% in Spring 2015, moved to 46% and 41% in Fall 2015 and Spring 2016 respectively, and finally in Fall 2016, 64% of the students think flipped classroom helped them with the academic content. The last semester was the one in which students had the leading role in the class discussions and this must have positively impacted their overall experience. In contrast to this finding, when the students were asked whether they would like to use flipped classroom format in other courses (Q9) or to use it more often in the class (Q12) the data show that they are not totally convinced to use it more. The authors argue that it could be due to the normal students' resistance to change after many years submerged in a traditional way of teaching, and that more extensive experience with this type of teaching might lead to different opinions.

Some of the questions in the survey were formulated to analyze the impact of the implementation on student motivation and engagement. Q2 (When in a flipped classroom format my participation increases) addressed the motivation and the results are intriguing since the answers show that the students do not find their class participation increased in the flipped format. It might be hypothesized that the hybrid set-up of the class impacted these answers, but only more experiments or more detailed surveys can bring clarification in this matter. Several questions are related to students' engagement: Q5 (Using flipped classroom format encourages me to spend more time preparing for class), Q6 (Learning with flipped classroom format gives me confidence to ask more questions), and Q7 (Using flipped classroom format encourages me to attend more classes). The data show that with the improved implementation as the experiment progressed over the four semesters, the students felt more engagement. The turning point was definitely in Spring 2016 when the students took the discussion lead during in-class activities. The answers of these questions balance the answers of Q2, since the majority of students find the flipped classroom format to promote class discussions and to make them more confident in asking questions. It seems that students do not necessary find that asking questions and more engaged discussions are part of increased class participation. They might have been considering the actual leading role of the discussions as active participation.

Another aspect of the analysis of the survey is related to the students' opinion on how flipped classroom helped them during the different stages of learning: acquisition (Q4 and Q14), generalization (Q15), and maintenance (Q13). The results show that the highest positive rates were recorded for the acquisition part of the learning process, especially as the students perceived the flipped format implementation better overall (Fall 2016). One of the main goals of implementing flipped classroom model was to find a better way to help student understand the class material and these results show that this goal was achieved. Question Q15 shows that even for the generalization aspect of learning students found the flipped classroom format beneficial. It is important to note that large majority of students agreed with this aspect, regardless of the overall opinion on the actual implementation. The maintenance aspect of learning was the least observed, but question Q13 may be used to conclude for a positive student feedback in this matter.

Students' critical thinking was also surveyed through questions Q6 (Learning with flipped classroom format gives me confidence to ask more questions), Q8 (Using flipped classroom format promotes more focused discussions during the class), and Q15 (Using flipped classroom format helped me learn how to apply the concepts to practice). Questions Q6 and Q8 show an increasing trend of positive answers, indicating a correlation between the overall perception of the class and positive impact on critical thinking.

In order to gauge the students' overall opinion on the flipped classroom model implementation, averages of the positive, undecided, and negative answers were compiled in Table 4. There is a clear pattern of improvement as the experiment progressed along the semesters. The survey data was also processed to observe the results from the whole cohort in relation to the group of students who watched most of the videos (as the group that showed most interest in the class) and to the group of students with average GPA (between 2.5 and 3.5). The results for groups show the same trend of data, but the numbers indicate higher positive rates for the group of students that showed serious interest in the class.

Table 4. Average percentages of the positive, undecided, and negative answers over all 15 likert questions.

				
From all students	Spring 2015	36%	26%	38%
	Fall 2015	40%	30%	30%
	Spring 2016	40%	30%	30%
	Fall 2016	54%	21%	25%
From students who watched most of the videos	Spring 2015	39%	27%	34%
	Fall 2015	44%	33%	23%
	Spring 2016	50%	23%	27%
	Fall 2016	57%	20%	23%
From students with GPA higher than 2.5 but below 3.5(*)	Spring 2016	38%	30%	32%
	Fall 2016	51%	23%	26%

(*) The GPA question was introduced during Spring and Fall 2016.

In Fall 2016 the survey included some open-end questions, for which 39 out 52 students that took the survey answered. 11 students did not make any suggestions but they only had some positive comments. 3 students had negative comments but made no suggestions either. The rest of the participating student showed interest in the feedback process and included suggestions in their answers. Some of the positive comments were: "Watching Flipped Lectures helped start me off on the right foot with the following lecture," "I like the format of the flipped classroom from this class much more than just being told to read before class. Actually having a lecture for the flipped portion was much better," "It seems to work pretty well for this class and really does benefit the learning environment," "I feel that the format was used a correct amount of times. Some people like myself learn well by doing instead of watching. This allows us to get a little more hands on experience with the problems," "I believe that there should be more flipped classroom lectures assigned. It helped me understand topics that were only briefly discussed in class due to time concerns. I enjoyed the ability to watch the recorded lectures on my own time. I felt like they helped enhance the in class experience," "This worked best for me, really liked it."

Some students did not adjust to the flipped classroom environment and some negative comments were: "Not use it. If you need to skip around in the book then do so. It is confusing and hard to follow," "I found the entire 'flipped classroom' concept to be pointless," "I was confused with teaching throughout the year. I tried to teach myself the material because I could not understand what was going on in class."

Among the suggestions provided by the students, two of them suggested to have more flipped lectures, few made suggestions regarding the in-class activities, including enforcement of attendance in order to increase participation, more sample problems, and for the instructor to post the questions in written such that the students to better focus on them. Three students proposed to increase the number of students watching the recorded videos before the class, through short quizzes or by scheduling the videos to be watched during the weekends. Students did not make suggestions relative to the length of the videos, and this indicates that video length is not a major concern. Since the videos used in this experiment were pre-recorded during an actual semester prior to the flipped classroom experiment, some suggestions made by the students were to edit these recordings or were comments relative to their quality.

Instructor perspective

This experiment was facilitated by the availability of the pre-recorded videos from previous hybrid, face-to face and online, course delivery. The flipped classroom set-up made available more class time for problem solving, but when student–instructor roles were inverted, and students were leading the discussions the pace of the class was slow and no more than 2-3 problems were covered per class. There is more to do on this regard to cover more problems without cutting much the natural flow of the students' discussion.

From instructor perspective the flipped classroom format was beneficial to all students. The class was more dynamic and the students were more engaged, particularly the online participants. The whole process seemed to have elevated students' confidence in their abilities. The students engaged in actual debate of the step-by-step solutions to the problems, which is an evidence of functioning critical thinking.

The topics where flipped classroom was applied have been always assessed on the 2nd test of the semester. The student outcomes for that test are: 1) explain the fluid dynamics in pipes and fittings; 2) apply the principles of conservation of energy (Bernoulli's equation) and mass to fluid flow systems; and 3) compute friction losses in pipes for a variety of configurations (series, parallel, network, etc.). Table 5 shows the course average grade for that particular test throughout the semesters the instructor has taught the class at the institution. Fall 2013 and Fall 2014 were taught following traditional classroom. There is no clear pattern, neither clear change in the student's performance. Interestingly, the semester that the students' perception on technique was better was when the students did worst on the 2nd test. If anything, the grades were not notable influenced by the teaching technique but at least they did not get hurt. Note that the semester averages between S15 and F26 were relatively above the overall average. This is consistent with the results of other similar studies [1].

Table 5. Course average grade for the test where flipped classroom topics were assessed.

Fall 2013	Fall 2014	Spring 2015	Fall 2015	Spring 2016	Fall 2016	OVERALL AVERAGE
68	56	70	69	68	66	66.17

The instructor has noted that most of the students that drop the class (officially or not) they do it right after the 2nd test. Data show a decreasing trend for drop out and/or fail, as illustrated in Table 6, and this may be evidence that the flipped format had positive impact on students' performance in the class. The results might be simply due to more problem solving under instructor supervision, and other ways of providing this may bring the same improvements. Only some comparative studies between different class techniques can bring actual support that flipped classroom method is effectively contributing to students' success. To have a better baseline for comparison, flipped classroom method will not be used during Spring 2017 and the results of this semester will be compared with those from the previous flipped classroom implementations.

Table 6. Percentage of students during flipped classroom implementation that dropped or failed the class.

Spring 2015	Fall 2015	Spring 2016	Fall 2016
44%	32%	34%	15%

Conclusions

This paper presents a study of flipped classroom implementation in a Fluid Mechanics class in a Engineering Technology Department at an midsize university. The main constraint of this case study was the hybrid class setting, with students attending either in person or virtually (online) the class. The online students could watch the lecture synchronous (and have the chance to actively participate to the discussions) or asynchronous (and be only observers to the problem solving process). The study span over four semesters and changes were made as the study progress to better address the challenges of the implementation. Most of the changes were in the attempt to determine more students to conscientiously watch the pre-recorded lectures before the in-class activities. The best strategy was to require the students to take notes as they watch the lecture, and submit those notes for grading, along with the activation of the tracking feature in Blackboard. Another important finding of the study is that the best received implementation of the flipped classroom methodology was when students took lead in the discussions of the problem solving. The class discussions were concluded with a post-class activity in which the students were asked to formally edit the solutions discussed, with step-by-step procedure detailed and full numerical calculations. Thus, the learning process consisted in three phases, an individual study time based on pre-recorded lectures, a group study time of problem solving and debate, and another individual study time, more of a reflection time in this case, in which the whole learning process was rounded up and summarized in a final report. A survey was used to get feedback from the students after each implementation and the results of these surveys were discussed in the paper. Overall the students like the technique and found it beneficial in their learning process.

References

1. Velegol, S. B., Zappe, S. E., & Mahoney, E. M. I. L. Y. (2015). The evolution of a flipped classroom: Evidence-based recommendations. *Advances in Engineering Education*, *4*(3), 1-37.
2. Kerr, B. (2015, September). The flipped classroom in engineering education: A survey of the research. In *Interactive Collaborative Learning (ICL), 2015 International Conference on* (pp. 815-818). IEEE.
3. Mendoza Diaz N. V, Imbrie P.K., Muenzenberger A. (2015). The Inverted Engineering Classroom: An Analysis of the Impact in a First Year Engineering Program. *7th First Year Engineering Experience (FYEE) Conference*, August 3-15 2015, Roanoke, VA.
4. Yelamarthi, K., & Drake, E. (2015). A Flipped First-Year Digital Circuits Course for Engineering and Technology Students. *IEEE Transactions on Education*, *58*(3), 179-186.
5. National Research Council (2011) - Committee on Highly Successful Schools or Programs for K-12 STEM Education (2011). Successful STEM education: A workshop summary.
6. Lape, N. K., Levy, R., Yong, D., Haushalter, K., Eddy, R., & Hankel, N. (2014). Probing the Inverted Classroom: A Controlled Study of Teaching and Learning Outcomes in Undergraduate Engineering and Mathematics. *121st ASEE Annual Conference & Exposition*, June 15-18 2014, Indianapolis, IN.
7. Furse, C. (2013, July). A busy professor's guide to sanely flipping your classroom. In *Antennas and Propagation Society International Symposium (APSURSI), 2013 IEEE* (pp. 2171-2172). IEEE.
8. Lin, J. L., Imbertson, P., & Moore, T. (2014, October). Classroom discourse development for" Flipping classrooms": Theoretical concepts, practices, and joint efforts from engineering students and instructors. In *Frontiers in Education Conference (FIE), 2014 IEEE* (pp. 1-8). IEEE.
9. Sahin A., Cavlazoglu B., and Zeytuncu E. (2015). Flipping a College Calculus Course: A Case Study. *Journal of Educational Technology & Society*, 18(3), 142-152.
10. Hotle S. and Garrow L. (2015). Effects of the Traditional and Flipped Classrooms on Undergraduate Student Opinions and Success. *ASCE J. Prof. Issues Eng. Educ. Pract.*, 05015005.
11. Kobus C. (2013). On Why the Flipped Classroom Model May Be the Optimum for Heat Transfer Education. *Proceedings of the ASME Heat Transfer Summer Conference.* July 14-19 2013, Minneapolis, MN.
12. Bishop J. and Verleger M. (2013). The Flipped Classroom: A Survey of the Research. 120th ASEE Annual Conference & Exposition, June 23-26 2013, Atlanta, GA.
13. Pelton T., Pelton L.F., and Sanseverino M. (2008). Clicker Lessons: Assessing and Addressing Student Responses to Audience Response Systems. *CELT – Collected Essays on Learning and Teaching*, 1, 85-92.
14. Popescu O., Chezan L., Jovanovic V., and Ayala O. (2015). The Use of Polleverywhere in Engineering Technology Classes to Student Stimulate Critical Thinking and Motivation. *122nd ASEE Annual Conference & Exposition*, June 14-17 2015, Seattle, WA.