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Evaluation of a Flipped Classroom in Mechanics of Materials

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Abstract

Recent interest towards the implementation of flipped (or inverted) classrooms parallels the wide availability of technology and the shift from lecture-based teaching methods towards student-centered teaching methods in undergraduate engineering education. The flipped classroom involves two components: computer based video instruction outside of the classroom and interactive learning activities inside the classroom. The intent is to create an active and engaging classroom experience that can be tailored to meet the needs of students possessing a wide range of learning styles. This can potentially reduce attrition, improve knowledge retention, and enhance skill development in engineering. The main goal of this study was to compare and contrast the effectiveness on student learning of a flipped versus a traditional lecture-based classroom in a first course in mechanics of materials. Two five-week summer session courses in mechanics of materials were used to conduct the study; one following traditional methods and the second in a flipped teaching format. Our assessment on the effectiveness of the flipped teaching method is based on performance of pre- and post-quiz scores. Statistical analysis of the pre-quiz and post-quiz data indicates that students in the flipped classroom (treatment group) performed better than those in the traditional classroom (control group) approach. Controlling for prior academic achievement and initial levels of content-specific achievement, a multiple linear regression analysis shows that 8% of the variability in post-quiz scores is accounted for by the instructional delivery approach used. Thus, there is evidence to suggest that participation in the flipped classroom results in better performance than participation in the traditional classroom.

Introduction

The flipped teaching model has garnered much interest among educators as the instructional approach to shift the traditional instructor-centered model towards a student-focused approach in classroom settings. Flipped teaching, or the inverted classroom, refers to the approach where most direct learning is shifted outside of the classroom using technology such as video lessons, interactive textbooks, or other online resources, which allows instructors to capitalize on students' preparation and focus in-class meetings on integrating and applying knowledge through student-centered, active learning strategies[1]. The primary appeal of the flipped classroom is the increased opportunity for instructors to implement learner-centered instruction that includes active learning, collaborative, cooperative, and problem-based learning techniques[1,2,3]. The benefits of student-centered environments are well documented in literature and have been demonstrated to promote student engagement, better student attitudes, improve retention, and increase motivation[2,4]. Over an entire course, the flipped classroom, like most instructional approaches, is intended to support students in achieving learning outcomes and to increase motivation towards their respective disciplines.

In addition to promoting a student-centered environment in the classroom, the use of flipped instruction has several advantages. Direct instruction outside of the classroom primes students for tasks in the classroom since they have already been exposed to particular stimuli[1]. Also, direct instruction prior to entering the classroom provides pre-training that can potentially reduce intrinsic cognitive load, which can reduce the mental effort required to learn new material[1,5]. A flipped teaching model also allows instructors to address student differences and appeal to a diverse range of learning styles by assigning a variety of learning tasks during a classroom session[6,7,8].

Determining the effectiveness of teaching methods in educational research requires examining the techniques employed, interpreting data carefully, quantifying the magnitude of a reported improvement, and determining if that improvement is statistically significant[2]. While the flipped teaching method has garnered much attention in the popular media, the benefits of the approach on student learning is not fully characterized in academic research, with evidence that is often qualitative, limited in quantifying the impacts of the flipped model, or inconclusive[1,4, 9]. For instance, there are questions associated with the appropriateness of a flipped classroom for different course levels with some researchers suggesting the approach is well-suited for advanced courses, while others have emphasized caution[8]. Some researchers have reported increases in depth of student understanding based on statistically significant improvements in post-test performance as compared to pre-test performance[10] and others have reported improvements in student satisfaction[11]. However, there are also reports noting less student satisfaction or no difference at all in a flipped teaching environment [12, 13]. These conflicting reports indicate that more rigorous empirical research is needed and that best practices have yet to be established to facilitate the use of a flipped teaching approach.

The goal of this study is to compare and contrast the effectiveness of a flipped classroom and a traditional lecture-based classroom in a first course in mechanics of materials. Two 5-week summer session courses in mechanics of materials were used to conduct the study. The first course was taught in a traditional lecture-based format where, during face-to-face meetings, new concepts were introduced during the lecture, example problems were solved by the instructor and in groups by students; outside of class students solved problems as part of homework assignments. The second course was taught using a flipped classroom approach where face-to-face sessions were used for active learning techniques involving group discussions, problem solving sessions, and demonstrations. Prior to and outside of class students were required to watch screencast tutorials on YouTube and answer concept questions; after class they completed additional homework problems. Pre- and post-quizzes were used to evaluate and to compare student performance between the traditional lecture course and the flipped instructional course. The following research questions are addressed in this study.

(1) Do students participating in a flipped instructional delivery section of an engineering course learn more than those in a traditional lecture-based section of the same course?

(2) After controlling for prior academic achievement (in general, using college GPA upon course entry) and initial levels of content-specific achievement (using pre-quizzes associated with each topic), do students participating in a flipped instructional delivery section of an engineering course perform better on content-specific achievement measures than those in a traditional section of the same course?

Methodology

A first course in mechanics of materials that is part of the general engineering curriculum at the University was used to evaluate the effectiveness of the flipped classroom approach. The course is required for bioengineering, Civil Engineering and Mechanical Engineering majors, or chosen as an elective by those majoring in Engineering Physics and Engineering Management. The course selected for this study is four semester credits and was taught over five weeks. The course was taught twice during the summer of 2014 in the first and third summer sessions, with the first session conducted as a traditional lecture-based course; and the second iteration of the course taught using a flipped classroom approach. Both courses met five days per week for 125 minutes each day resulting in 625 minutes of in-class meetings during a typical week. Each course was taught by the first author using Hibbeler's *Mechanics of Materials*[14] textbook. The topics were presented in the same order and exams covered the same topics for each session. Table 1 provides a list of topics covered in both courses with topics taught using a flipped approach in the second session identified in the approach column. Since only seven of the topics were taught following a flipped teaching approach, the course would be categorized as a partial flip. However, the key concepts of stress and strain were taught using both approaches early in the terms, making the comparison between the two approaches pedagogically pertinent.

In order to evaluate the effectiveness of the flipped classroom approach, a quasi-experimental design was utilized because the students self-enrolled into one of two sections of the same engineering course. Both the treatment and control groups were samples of convenience. However, they are representative of the general population that includes engineering students within a private, liberal arts university with a school of engineering offering ABET accredited programs in bio, civil, and mechanical engineering who enroll in a first course in mechanics of materials. The control group is identified as the traditional classroom and the treatment group is identified as the flipped classroom. Table 2 provides a comparison of typical teaching methods and activities used as part of the traditional and flipped classrooms in this study.

While the traditional approach of instructor-led discussion and application/example problems are typical of general engineering courses, the flipped classroom approach differed in multiple ways. First, in the latter, students were required to watch online classroom videos of topics prior to the relevant lecture and were thus pre-trained. It is unknown if required readings with short answer questions would have resulted in the same effect. Second, the flipped classroom provided pre-training of students in topics to be covered in the classroom reducing the instructor's need to lecture and provide the first exposure to a topic. Since students had attained prior knowledge, discussion at the beginning of class focused on clarifying difficult concepts and answering questions posed by students. Third, while active learning techniques were employed for both the treatment and control groups, in the treatment group (flipped classroom) the quality or depth of activities went beyond basic identification or lower levels of Bloom's taxonomy. Rather, questions posed for think-pair-share activities challenged students to develop their own answers for "why" a topic was critical, create a flowchart describing the problem solving approach, or investigate the effect of design parameters (i.e., geometry and loading) on stresses. In addition, the increased time available in the classroom, as noted by many other researchers (as discussed in the introduction) allows for more personalized coaching, peer-to-peer instruction and other activities intended to motivate students. For instance, in-class problem solving competitions and problem solving in a simulated exam environment (by introducing time constraints) can be covered.

Table 1. List of topics covered in each course

Topic	**Approach**
Internal Loading, Reactions, and Stress Definition	
Average Normal Stress and Average Shear Stress	Flipped
Design of Simple Connections	Flipped
Normal Strain and Shear Strain	Flipped
Mechanical Properties of Materials	
Axial Deformation	Flipped
Principle of Superposition and Force Method	
Statically Indeterminate Axially Loaded Members	
Thermal Loading	
Torsion Formula	Flipped
Power	
Angle of Twist	
Statically Indeterminate Torsionally Loaded Members	
Internal Shear and Moment Diagrams	Flipped
Flexure Formula	
Unsymmetric Bending and The Shear Formula	
Transverse Shear	Flipped
Shear Flow in Built-up Members and Thin Walled Members	
Pressure Vessels	
Combined Loading	
Stress Transformation: Plane Stress, General Equations	
Principal Stresses, Max In-plane Shear Stress, Mohr's Circle	
Design of Beams	
Deflection of Beams and Shafts by Integration Method	
Statically Indeterminate Beams	
Column Buckling: Critical Load	

Description of Groups

The traditional classroom (control group) consisted of 11 students of which 4 were female (36%). The flipped classroom (treatment group) consisted of 15 students of which 4 were female (27%). The difference in these two proportions was not significant (p = .597). The groups were not found to differ to a statistically significant extent in terms of prior academic achievement [$t(24) = -0.838$, $p = 0.41$, two-tailed] nor performance in the prerequisite course [$t(24) = -1.391$, $p = 0.177$, two-tailed]. However, the groups did differ in terms of the average points earned on the pre-quizzes associated with the course topics [$t(20.532)= 2.514$, $p = 0.02$, two-tailed]. This difference is likely attributed to the timing of the pre-quizzes, since the treatment group viewed videos and completed conceptual questions prior to the administration of the pre-quiz. See Table 3 for a detailed statistical analysis.

Table 2. Teaching methods and activities employed in traditional and flipped classrooms

	Traditional Classroom	**Flipped Classroom**
Outside of Classroom	▪ Readings were suggested daily ▪ Daily homework assignments with problems selected from the textbook	▪ Online videos were assigned for viewing ▪ Answer and submit short answer questions before the start of class ▪ Daily homework assignments with problems selected from the textbook*
Inside the Classroom (Face-to- Face Sessions)	▪ Instructor introduces concept/theory/derivation through a traditional lecture ▪ Instructor demonstrates application of concept with example calculations ▪ Active learning exercises were implemented to create a more interactive learning environment with time permitting (i.e., think-pair-share, muddiest point, group problem solving) ▪ Pre/post quizzes were conducted at the beginning and conclusion of each topic	▪ Instructor reviews central concepts from the online videos ▪ Active learning exercises were implemented (i.e., think-pair-share, muddiest points, creating problem solving flow charts, identifying applications, group discussion, etc.) ▪ Instructor demonstrates application of the concept with example calculation ▪ Pre/Post quizzes were conducted at the beginning and conclusion of each topic

* a fewer number of problems were assigned for the flipped classroom as compared to the traditional classroom

Table 3. Comparison of groups before the intervention.

	Group	**N**	**Mean**	**Std. Deviation**
Grade in Prerequisite Course (in GPA units)	Treatment (Flipped)	15	2.67	0.728
	Control (Traditional)	11	3.06	0.677
Prior College GPA	Treatment (Flipped)	15	3.00	0.552
	Control (Traditional)	11	3.18	0.528
Average Performance on Pre-quiz	Treatment (Flipped)	15	.121	0.129
	Control (Traditional)	11	.0260	0.058

Note: The pre-quiz score is an average based on at least 5 of the 7 pre-quizzes given throughout the course, prior to coverage of content in face-to-face meetings.

Instrumentation

The first author, who taught the courses also created the achievement measure aligned to the curriculum, with separate quizzes for each major topic. Separate questions were selected by the instructor as pre- and post-quiz problems and reviewed by the third author to verify comparable levels of difficulty. Although no formal evidence was gathered as to the reliability and validity of the quiz problems, as the first author is an expert on the topic of this course, it is expected that the items are representative of the domain of study (i.e., the quizzes possess content validity). In addition, scoring of the student responses was done consistently by the first author (i.e. ensuring their reliability).

The same sets of pre- and post-quizzes were given to the control and treatment groups. The dependent variable was the average performance on the post-quizzes given across seven different topics covered in the course. Although there were additional topics covered within the course, because neither group was exposed to a flipped version of those topics, performance on quizzes associated with those additional topics were not included in the calculation of either the average post-quiz or the average pre-quiz score.

Table 4 shows three different pre- and post-quizzes selected from the course textbook[14] used in both the traditional lecture and flipped courses. The pre-quizzes were administered during in-class time at the start of the meeting. Similarly, for the flipped classroom the students were expected to have completed video assignments prior to the in-class meetings, which was prior to the pre-quiz and thus have experienced some pre-training in addition to suggested readings. The post-quizzes were also administered in class following the completion of instruction of a given topic. During the summer sessions pre- and post-quizzes were administered in the same day, therefore students did not have the advantage of practicing application of concepts on problem sets outside of class between pre- and post-quizzes.

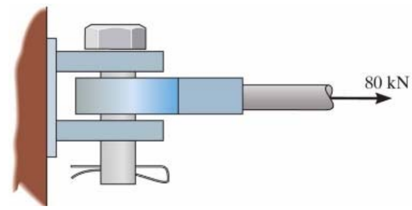
Generally, each quiz was scored as 1 for correct or 0 for incorrect. An accurate numerical answer with appropriate units constitutes a correct answer; while an accurate numerical value with incorrect units was scored a zero. Thus the mean is equivalent to the average of the percentage of points earned across the quizzes that students took. All students completed pre- and post-quizzes for at least five of the seven topics. Thus, the means were based on a minimum of five quizzes per student. Requiring each case to have completed all seven quizzes would have reduced the sample size further, compromising the statistical power of the analysis.

The independent variable was the type of instructional delivery the student received, traditional or flipped. Prior college GPA, grade earned in the prerequisite engineering course, and average performance on the pre-quizzes served as control variables, to account for initial differences between the groups that arose from the lack of random assignment, given that it was necessary to employ a quasi-experimental design for this study. The average performance on pre-quizzes (one of the control variables) was calculated in the same way as described above for post-quizzes (the dependent variable).

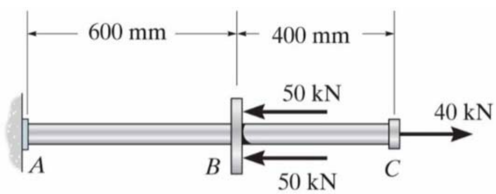
Table 4. Examples of pre- and post-class quizzes used to compare student performance.

<table>
<tr><th>Pre-quiz Problem Statements</th><th>Post-quiz Problem Statements</th></tr>
<tr><td>The nails are made of a material having an allowable shear stress of 40MPa. Determine the minimum required diameter of each nail if P = 90 kN.

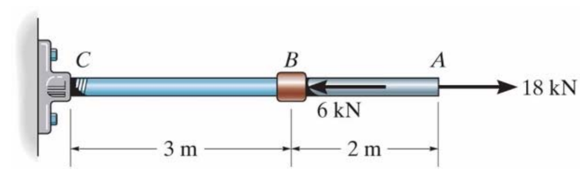
</td><td>The pin is made of a material having an allowable shear stress of 40 MPa. Determine the minimum required diameter of the pin to the nearest mm.



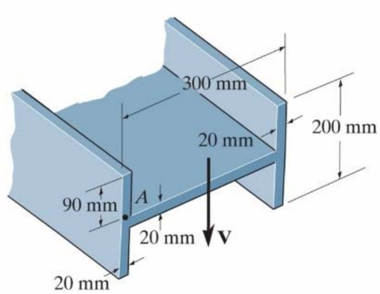
</td></tr>
<tr><td>The 20 mm diameter steel rod (E = 200 GPa) is subjected to the axial forces shown. Determine the displacement of end C with respect to the fixed support at A.



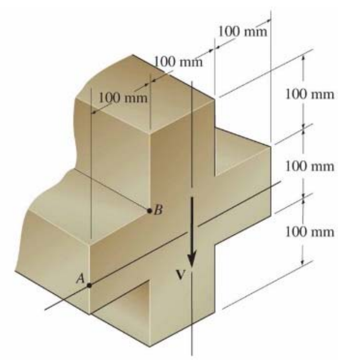
</td><td>The assembly consists of a steel rod *CB* (E_{st} = 200 GPa) and an aluminum rod *BA* (E_{al} = 70 GPa) each having a diameter of 12 mm. If the rod is subjected to the axial loadings at *A* and at *B*, determine the displacement of end *A* with respect to the fixed support at *C*. Neglect the size of connections at B and C, and assume that they are rigid.



</td></tr>
<tr><td>If the beam is subjected to a shear force of V = 100 kN, determine the maximum shear stress developed at point A.



</td><td>If the beam is subjected to a shear force of V = 600 kN, determine the shear stress developed at point B.



</td></tr>
</table>

(Problem statements and figures are from *Mechanics of Materials* by Hibbeler[14])

Results

To address the first research question as to whether students participating in a flipped instructional delivery section of an engineering course learn more than those in a traditional (lecture-based) section of the same course, descriptive statistics showing the means and standard deviations for each group on both the pre- and post-quizzes, and the change from pre- to post-quizzes were calculated (see Table 5). The mean change scores (i.e., post-quiz – pre-quiz) were compared between the two groups using an independent-samples t-test. The change in mean of the treatment group ($\Delta = 0.46$) did exceed that of the control group ($\Delta = 0.36$) and it was found to be marginally significant, $t(24) = 1.528$, $p = 0.07$ (one-tailed).

Table 5. Descriptive statistics for pre-quiz, post-quiz, and change by group.

Group	Measure	Mean	Standard Deviation
Flipped Treatment Group (*n* = 15)	Post	0.58	0.23
	Pre	0.12	0.13
	Change, Δ	0.46	0.20
Traditional Non-flipped Control Group (*n* = 11)	Post	0.38	0.14
	Pre	0.03	0.06
	Change, Δ	0.36	0.14

To address the second research question as to whether, after controlling for prior academic achievement and initial levels of content-specific achievement, students participating in a flipped instructional delivery section of an engineering course perform better on content-specific achievement measures than those in a traditional section of the same course, multiple linear regression was employed. Control variables, prior academic achievement and initial levels of content-specific achievement entered in the first and second models, then the independent variable experimental group (treatment = 1, control = 0) entered in the third model.

Based upon all 26 cases, the sequential multiple regression[15] is summarized in Table 6, where it can be observed that prior academic achievement, as indicated by overall college GPA upon entering the course, accounted for about 4% of the variance; and initial levels of content-specific achievement as indicated by the average pre-quiz score (prior to instruction) accounted for an additional 26% of the variance. Moreover, after controlling for these two measures of prior achievement, the change in R^2 for Model 3 indicates that the type of instructional delivery used (flipped or traditional) accounted for an additional 8% of the variability in post-quiz scores. Combined with the results shown in Table 7, it can be noted that the regression coefficient for the Experimental Group was +0.145 and its associated one-tailed p-value approaches statistical significance (given that the results were in the predicted direction). In fact, given the small sample sizes available and exploratory nature of this study, some researchers would possibly adopt 0.10 as the alpha level and claim that the one-tailed result, $p = 0.0505$, is statistically significant. Thus, this provides evidence to suggest that participation in the flipped section of the engineering course resulted in better course performance than participation in the traditional section. In addition, as cited by other researchers[3,16], the flipped classroom experience at worst was not detrimental to student learning, and, at best improved student learning.

Table 6. Sequential multiple linear regression model summary

Model	**Variables Added**	***R^2***	***Change in R^2***	***Change Statistics***
1	College GPA: prior academic achievement	0.041	0.041	$F(1,24) = 1.031$, $p = 0.320$
2	Average Pre-quiz Score: initial levels of content-specific achievement	0.306	0.264	$F(1,23) = 8.761$, $p = 0.007$
3	Experimental Group (1 = Treatment, 0 = Control)	0.387	0.082	$F(1,22) = 2.931$, $p = 0.101$

Table 7. Multiple linear regression coefficients of the full model.

Variables in Final Model	***B***	***SE_b***	***β***	***t***	***p (two-tailed)***
Constant	0.197	0.246	--	0.801	0.432
College GPA: prior academic achievement	0.053	0.077	0.132	0.689	0.498
Average Pre-quiz Score: initial levels of content-specific achievement	0.691	0.395	0.365	1.750	0.094
Experimental Group (1=Treatment, 0=Control)	0.145	0.085	0.339	1.712	0.101

Future Work and Conclusions

This paper presents a study comparing the effectiveness of two different instructional approaches, traditional lecture-based and flipped, for a first course in mechanics of materials during five-week summer sessions. The traditional lecture-based instruction entails assigning readings, followed by lectures where students are given the opportunity to reinforce the material they learned in the readings through lecturing, discussion and problem solving through active learning techniques; assessment is based on homework assignments and in-class examinations. The flipped instruction provides support and places more responsibility on students to pre-learn material using online videos and answering conceptual questions, followed by in-class activities that emphasize learner-centered active learning; assessment is also based on homework assignments (though not as extensive), in-class examinations and pre- and post- quizzes. The pre- and post- quizzes are also used in the traditional class in order to compare and contrast the quantity of learning that takes place in the classroom using the two different approaches.

As the references indicate, there is significant variability in results on the effectiveness of flipped teaching, from no improvement to statistically significant improvement. Our results are very promising and indicate statistical improvement in the effectiveness of the flipped approach. However, the results are based on two classes with small numbers of students; therefore, caution must be exercised in interpreting the results and additional studies should be conducted to completely validate these results. Suggestions for future research include implementation of the treatment by more than one professor, done in a variety of engineering courses, utilizing additional types of measures (such as performance assessments and projects) and, where possible, larger samples of students. Also, the timing of the pre-quizzes should occur prior to students beginning their on-line training. In this study, the results may actually be an underestimation of the flipped format's impact since the treatment group did view videos and complete conceptual questions on the topic prior to administration of the pre-quiz.

In sum, this study contributes to our knowledge base on effective instructional methods for teaching undergraduate engineering students. While exploratory in nature, with limited scope, the results do show the promise of a flipped approach on student learning in a first course on mechanics of materials. The following comments highlight the primary findings of this study.

- The comparisons of the results were normalized to account for certain factors such as prior academic achievement because the student samples were not random, given that students self-selected their corresponding section. A sequential multiple regression analysis was performed to determine how prior GPA, pre-class quiz score, and teaching approach contributed to the variation in post-class quiz performance. Results indicate that prior GPA accounted for 4%, pre-class quiz score accounted for an additional 26%, and the flipped classroom approach accounted for an additional 8% of the variance. Consequently, based on our results we can conclude that pre-training through online video views and the active learning environment associated with the flipped classroom improves student learning in mechanics of materials. It should be noted that the percentage accounted for by the pre-class quiz and teaching approach are both indicators of the flipped intervention, given that we controlled for prior academic achievement in the first block of the sequential multiple regression. Thus, the pre-class and in-class activities of the flipped approach, in combination, may jointly explain about one-third (26% + 8%) of the variation in post-quiz performance.

- Pre-class quiz score averages were greater for the flipped classroom (0.12) versus the traditional lecture classroom (0.03). This is attributed to the pre-training provided to students who were required to view videos and complete short answer conceptual questions whereas those in the traditional section simply had a list of suggested readings assigned. As noted above, this study did not address whether the pre-class activities described here that were used with the flipped section would result in better performance than a modified traditional condition where, prior to attending lecture, students respond to short answer questions. Future research should be conducted to investigate this empirical question comparing not only the pre-quiz but also the post-quiz performance since the two approaches may differentially prime the learner in terms of the impact of in-class activities.

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