Evaluation of a Flipped Classroom in Structural Steel Design

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Introduction

An upper-division structural engineering design course focusing on structural steel design was reformatted to follow a "flipped" classroom model. Flipped classrooms place greater emphasis on self-study for basic concepts to allow for more interactive, example-based learning during time spent within the classroom [1]. By spending more time preparing for a class, students often find themselves spending less time working to complete required assignments; thereby, students "flip" the way they allocate their time. Further, time spent within the classroom becomes the second meaningful exposure point for a concept or topic, with their pre-class preparation activities being the first exposure point. Therefore, students are one-step ahead when entering the classroom and attempting assignments, typically resulting in faster time to complete assignments and higher grades [1].

In the course discussed in this paper, students were required to watch videos (averaging 15 minutes in length) prior to each lecture-based class, with the videos focusing on introducing concepts, theories, or equations in structural steel design and demonstrating how the American Institute of Steel Construction Manual (AISC) codifies these concepts and theories for the purpose of design (i.e., low-level Bloom's taxonomy objectives such as remembering and understanding [2]). Time within the classroom typically focused on the practical application of these concepts and theories through examples as well as project-based learning (i.e., mid and high-level Bloom's taxonomy objectives such as applying, analyzing, and evaluating [2]). The expectation was students would spend a similar amount of time studying for the course when compared to the prior year (when the course format followed a "traditional" model with classroom time dedicated to theoretical knowledge and less time allocated towards collaborative discussion or design evaluations [3]), but allocate their time differently, resulting in increases to student performance and student satisfaction. In an attempt to add to the knowledge base of flipped classroom experiences in upper-division and structural engineering design classes, this paper explores the changes implemented to the course and provides an assessment of the modified course, with specific focus on student performance and student satisfaction.

Background

Flipped classrooms have a major difference compared to traditional lectures in that passive lecture content (e.g., theoretical behavior, derivations) is typically assigned as independent preparation activities (e.g., watching videos, reading book chapters) completed prior to class [4]. As a result, time spent inside the classroom can be focused on active and/or application-based learning [5], and course content can be modified to increase the complexity of examples and/or introduce more rigorous concepts [6]. Flipped classrooms have shown to improve many aspects of engineering education, including increases to student interest [7], student satisfaction [8], and student attitude [9]. In addition, student performance has shown to improve within flipped classrooms, including increasing the pass rate and decreasing the quantity of lower grades [10]. Flipped classrooms also allow for more interactive and collaborative learning opportunities within the classroom, a critical aspect when teaching any engineering design course [11].

Nevertheless, flipped classrooms have not always proven successful. The largest concern is with students who do not place their emphasis on preparation activities, resulting in the inability to engage in more complex and application-based examples within the classroom [12]. Student performance can be negatively impacted, as grades are heavily dependent upon good preparation habits [13] and follow-up assignments are often needed to allow for more productive classroom time [14]. Further, student satisfaction can suffer, as students cannot as easily or quickly ask for assistance during independent preparation activities [15]. As a result, more quantitative data is needed towards determining the key parameters within successful flipped classrooms [16].

In addition, there is a shortage of flipped classroom studies available that have focused on upper-division and structural engineering design courses. These studies have reported varying results. Some have shown little improvement in terms of student performance [17] and student engagement [18], while others have shown a significant increase in student learning [19] and student satisfaction [20]. Gross and Musselman [21] performed a five-year study that focused on inverted classroom experiences in upper-division structural design courses. The assessment focused on student performance (through exam grades) and student satisfaction (through student surveys) and demonstrated that students increased not only their fundamental knowledge of course material, but also their ability to apply that knowledge within a design setting. Student preparation was viewed as a major component towards creating a successful classroom experience. While this study provided both long-term and detailed assessments of a structural steel design class and a reinforced concrete design class, there are no other available publications to-date that involve flipped or inverted classrooms in structural engineering design courses.

Objectives

This paper intends to expand upon the limited available knowledge basis of flipped classroom experiences in upper-division, structural engineering design courses by assessing the changes implemented to a structural steel design class. In order to ensure a successful flipped classroom experience for the students, the following primary course objectives were established:

1. Ensure the adequate preparation of students prior to their time spent within the classroom (used to satisfy low-level Bloom's learning objectives).
2. Increase the application-based activities within the classroom (used to satisfy mid-level Bloom's learning objectives)
3. Expand the collaborative and project-based learning concepts within the classroom (used to satisfy high-level Bloom's learning objectives).

The effectiveness of the course objectives towards providing a positive flipped classroom experience will be assessed using quantitative data, student performance data (via course grades), and anonymous student feedback (using course evaluation surveys). This is an initial and limited study; a full assessment of Bloom's learning objectives is outside the scope of this paper.

Course Structure: Preparation Activities

Course meetings were scheduled three times a week for 75 minutes each meeting. A flipped classroom model was followed twice a week (referred to as lectures), with one meeting per week focused exclusively on collaborative and project-based learning (referred to as design meetings). Students were required to watch one video prior to each lecture (with the exception of exams and exam preparation classes). The videos are screen captures of PowerPoint presentations in which the instructor serves as the narrator and ranged from 8 to 25 minutes in length, with the average length about 15 minutes. The videos focused on introducing concepts, theories, and/or equations in structural steel design and demonstrating how the AISC Manual codifies these concepts and theories for the purpose of design. The learning objectives for the videos typically focused on low-level Bloom's taxonomy categories such as remembering and understanding [2]. The creation of each video was a significant process. Including the time to make the PowerPoint presentations, develop the talking points for the narration, and record and edit the videos, the average production time for one video was about 8 hours.

The recording of the videos was consistent with the presentation style of the instructor within the classroom. In other words, the narrations were not read from a script at a slow pace with a deliberate tone. Rather, the videos intentionally featured a slightly faster talking speed than a typical classroom lecture and longer pauses were only used when switching between topics or concepts within a video. Students were asked to pause the videos when taking notes, have their AISC Manuals open while watching the videos, and/or re-watch sections that may be unclear upon their initial exposure. As a result, almost all of the students watched the videos at 1x speed. When accounting for time to take notes, the self-reported preparation time of the students for each lecture was typically two or three times the length of the video.

Course Structure: Classroom Activities

Time within the classroom was focused on the practical application of concepts, theories, and equations in structural steel design through examples, typically targeting mid-level Bloom's taxonomy objectives such as applying and analyzing [2]. The expectation was that students would spend a similar amount of time studying for the course when compared to prior years, but allocate their time differently, with a greater focus on preparation work prior to the start of an individual class. Note that in the prior version of the course, these lecture-based classes would include both explanation of concepts and theories as well as examples focuses on the application of these concepts and theories. However, by implementing the flipped classroom model, classroom time during lecture was re-distributed towards additional and more complex examples as well as new topics in structural steel design (e.g., design of moment connections and design of composite sections). No other changes were made in the structure or format of the course.

Lectures typically consisted of two components: "Discussion" and "Demonstration." During "Discussion," students were randomly selected (using a random number generator in MATLAB) to answer questions regarding major concepts covered within the videos. In an effort to engage students who did not entirely understand the concepts presented within the videos, students were given the opportunity to ask clarification questions regarding the contents of the videos before discussion questions were revealed and random students were selected. Further, when answering the questions, students were allowed to use any individual notes they created while watching the videos. Examples of the discussion questions include:

- What does a large shear lag value indicate for tension members?
- As the relative stiffness of a connection gets larger, how will it impact the physical behavior of the compression members within the connection / frame?
- How is the behavior zone of a flexural member determined?
- For full-penetration groove welds, why is the strength of the base metal the only consideration per AISC (and not the strength of the filler material)?

Participation points (worth 5% of the course grade) were awarded based on the quality of the answers as determined by the instructor. During each lecture, approximately 25% of the students were selected to answer a question and the segment of class typically lasted 10 to 15 minutes. Over the duration of the course, all students were selected between three and eight times (with a mean of five selections). The purpose of the "Discussion" portion of lecture was to incentivize students to watch the videos and take notes, as well as to review and reinforce the major concepts covered within the videos. Assessing a student's performance during classroom time and in front of their peers was a critical and necessary step towards ensuring adequate student preparation (allowing the remainder of the classroom time to be used in a productive manner), as it held students accountable for their individual work.

During "Demonstration," analysis and design examples employing the concepts learned within the videos were presented and solved. As a result of the content covered in the videos, previously allocated lecture time was now available to provide more examples as compared to prior years. Within a module (where modules were separated by member types, such as tension, compression, or bending), initial examples focused on developing a comfort with basic member behavior and the use of the equations within the specifications for the AISC Manual. In the middle of a module, the examples focused on member analysis and the elements of complexity were typically increased throughout a class period. Examples at the end of a module focused on member design and the use of the design aides within the AISC Manual. While the majority of the examples were instructor lead, almost all lectures required students to assist in finding solutions using the think-pair-share (TPS) collaborative learning strategy, in which students think individually and share their ideas with classmates. TPS examples are a powerful learning tool and help student identify areas of weakness if they struggle while attempting to solve a problem. Since TPS examples can take more time to execute, they could be more easily and regularly included within a flipped classroom model. Finally, if all of the examples planned for a lecture were completed, lecture occasionally ended early to acknowledge and reward students for their additional time spent preparing for each class. This was an important mechanism to help students "buy into" the flipped classroom model, as students were unlikely to immediately realize the time saved on homework assignments or their improved performance on exams. This section of class typically lasted 60 minutes.

Once a week, time spent within the classroom focused on the semester long design project (referred to as design meetings). The design project focused on the direct application of classroom concepts towards a real structural engineering project (based on the work of an international structural engineering design and consulting firm) and featured the integration of current design codes/standards and the use of commercial software. Students were organized into small groups (for four or five students) based on the results of a self-assessment survey that measured their abilities in project management, technical documentation, technical calculations, and computer modeling. Each group was tasked with designing a five-story annex to an existing hospital structure. The project was not open-ended, as all student groups were provided with an architectural plan for the building, a basic structural layout (consisting of a structural grid and column locations), as well as the dead loads and live load occupancies on each floor level. Within their groups, the students determined the design loads, developed a computer model of the structure, selected the most appropriate member sizes for the beams and columns, and compiled a report, calculation set and structural drawing package describing their design process and final design. Throughout the semester, the feedback loop within a design office was emulated through a series of intermediate deliverables, which served to provide instructor comments to students (allowing them to make corrections) while ensuring the teams remained on-track with their final objectives. The learning objectives of the design meetings typically targeted high-level Bloom's taxonomy objectives, such as evaluating and creating [2]. In prior versions of the course, a similar format was used for course project. Nevertheless, the students' ability to function within the collaborative learning environment of the design meetings and apply their knowledge obtained during lecture towards completing the design project would serve as a comparison to evaluate the success of the flipped classroom model.

Assessment: Student Preparation

Video statistics were collected using the course website throughout the semester. There were 22 total videos to be viewed prior to lectures and 23 students enrolled in the class. As a result, there were 506 potential independent video views for the course. As shown in Table 1, the students viewed the overwhelming majority of the videos prior to attending class (only 1.8% views were missed). Further, the students typically watched the full-length of each video. A surprisingly moderate number of students watched the videos multiple times, as only 24.7% of the 506 potential video views were repeated more than once. However, during anonymous course evaluations surveys conducted at mid-semester, the majority of students reported they used their notes taken while watching the videos along with the PDF versions of the slides from the videos (which were posted online) to prepare for exams rather than repeat viewing the videos.

Table 1. *Video Views*

Video Parameter	No.	Perc.
Full-Length Video Views	485	95.8%
Partial-Length Video Views	12	2.4%
Missed Video Views	9	1.8%
Repeated Video Views	125	--

Table 2 provides a summary of the student participation outcomes during the "Discussion" portion of lectures. Students typically displayed a solid understanding of the topics and concepts covered within the videos, as 87.8% of discussion questions were answered correctly. Further, there were only seven instances where a student missing from lecture with an unexcused absence was randomly selected (with three such occurrences on the Friday prior to mid-semester break). This was reflective of the attendance throughout the semester, a byproduct of the random selection of students to participate during each lecture as well as the student assessment occurring in front of their peers. Based on the data within Tables 1 and 2, the students appeared to have more than adequately engaged in their

Table 2. *Participation Outcomes*

Participation Outcomes	No.	Perc.
Correct Responses	101	87.8%
Incorrect Responses	7	6.1%
Unexcused Absences	7	6.1%

preparation activities and demonstrated their ability to remember and understand basic theories, concepts, and equations in structural steel design.

As a result of the videos, lecture time could be reallocated to feature additional examples throughout the semester. Table 3 shows the number of examples used during the flipped classroom model as compared to the traditional model (used the prior year). In addition to more than doubling the total number of examples used throughout the semester, the flipped course model included three new lectures devoted to topics and concepts in structural steel design that had not been covered during the traditional course model (e.g., design of moment connections and design of composite sections). Therefore, the course content not only featured a wider range of topics, but also provided more in-depth coverage of these topics. Further, students were given more repetitions in application-based design and analysis topics and obtained a deeper overall understanding of structural steel design. While not captured by grades, student participation during the "Demonstration" portion of lecture was dramatically enhanced, as students would typically beat the instructor to the key discussion points or takeaways during examples.

Table 3. *Examples Used in Lecture*

Lecture Model	Total Number of Examples	Avg. Examples per Lecture
Traditional	31	1.29
Flipped	68	2.83

Assessment: Student Performance

Table 4 provides a summary of student grades during the flipped classroom model as compared to the traditional model (used the prior year). It should be noted that the difficulty of homework assignments was intentionally kept similar for each version of the course to allow for comparisons. While improved grades were observed across many major course components, the largest gains were observed in homework average (worth 10% of the course grade) and the design project (worth 17.5% of the course grade), demonstrating that students were better able to apply their knowledge in both individualized application-based assignments (targeting mid-level Bloom's learning objectives) as well as within a collaborative and projected-based learning environment (targeting high-level Bloom's learning objectives). While not captured by grades, office hour visits featured students asking substantially better quality and deeper-thought questions (not quantitatively measured, but rather the subjective opinion of the instructor and teaching assistants). Evening office hours conducted by student assistants for homework assistance were infrequently attended and discontinued after mid-semester break due to the lack of student need.

Table 4. *Student Grades*

Lecture Model	Hmwk	Design Project	Midterm Exam #1	Midterm Exam #2	Final Exam	Course GPA
Traditional	91.2	90.7	88.2	88.0	86.4	3.40
Flipped	94.3	94.0	87.5	89.4	87.7	3.64

When analyzing exam grades (each worth 22.5% of the course grade), no significant difference was observed in the mean exam scores. A higher overall course grade was observed, due to the increase in homework and project grades, a direct reflection of improvements in student preparation. Furthermore, it was observed that a smaller number of students performed at an unsatisfactory level. For example, in the flipped classroom model, 11.6% of exam grades were below 75% and no student received a C+ or lower for their final grade. For comparison, in the traditional class model, 13.9% of exam grades were below 75% and 9.3% of students received a C+ or lower for their final grade. The elimination of the "tail" in the final course grade was the result of students that did not perform poorly on multiple exams, possibly related to better week to week study habits. Note that the exams used within both course formats were different, but written with similar levels of difficulty. The incoming GPA of the students from each version of the course was comparable, indicating that the improved student performance was more closely related to both the changes to the course structure and student preparation habits as opposed to a different pool of students.

Assessment: Student Satisfaction

As a result of student participation, lectures were far more engaging and a rapport was developed among the students and instructor at a much faster rate. This is shown by the results of the end of semester course evaluation surveys completed anonymously by students (summarized in Table 5, where evaluation scores are rated on a 5.0 scale, except time studying outside of class). While student satisfaction was high in both versions of the course, the flipped model received higher evaluations for composite score (i.e., mean score of all survey questions related to the course) and effectiveness of teaching by the instructor. At the same time, students perceived the degree of intellectual challenge at a slightly lower level (likely due to the increased number of repetitions/examples presented during lecture) and self-reported to have spent less time studying outside of class on a weekly basis (despite the course covering more material at a greater level of depth and complexity).

Table 5. *Course Evaluation Surveys*

Lecture Model	Composite Score	Effectiveness of Teaching	Intellectual Challenge	Time Studying Outside of Class
Traditional	4.6	4.7	4.3	7.2-hrs/week
Flipped	4.8	4.9	4.1	5.7-hrs/week

In comments on both the mid-semester and end of semester surveys, students overwhelmingly articulated their appreciation for the videos, number of examples during lecture, and support for the flipped classroom model. The following are selected student comments regarding the course:

- "Putting in the extra effort up-front has helped my understanding."
- "… it maximized the usefulness of the time spend in class."
- "The concepts were usually where I get lost … so being able to rewind and pause the videos while learning concepts was very helpful."
- "I found it very helpful during examples when you would let us start the problem then finish it as a class. I was able to realize during these times that I may not have been understanding as much as I thought when I wasn't able to start it on my own and figuring this out in class is MUCH more helpful than during homework."
- "I spend much less time struggling with homework."

As shown by both the quantitative and qualitative data gathered during the anonymous student surveys, the student satisfaction within the course was enhanced as a result of the change to the flipped classroom model.

Conclusions

All of the parameters used to analyze the flipped classroom model definitively illustrate that the changes made to the course were positive. The course structure achieved the primary objectives to ensure adequate student preparation prior to time spent within the classroom as well as increase both the application-based and project-based learning activities inside the classroom. The success of the course was most directly related to the students embracing their preparation activities prior to each lecture, thereby allowing for more classroom time to be spent on new course content and an increased quantity of analysis and design examples, resulting in a greater understanding of structural steel design as well as the project-based learning concepts. In motivating students to accept their preparation activities, the videos were kept short (with an average length of 15 minutes) and focused on no more than a few topics. While tethering a graded participation assignment to the student preparation activities is not unique, it is a crucial and necessary step to help ensure adequate student preparation. Incorporating the assignment within the classroom as part of a discussion conducted in front of student peers does distinguish this flipped classroom model and proved to be successful. As a result of the changes to the course model, students were better prepared for assignments, resulting in observed improvements in student performance, including higher overall grades, better quality of questions and discussions during lecture, and the increased ability to translate skills and knowledge from lecture to the design meetings within a collaborative and project-based learning environment. The course improvements were met with overwhelmingly positive feedback from the students, as indicated by the results of the anonymous student feedback surveys conducted at both the mid-semester and end of the semester. A full assessment of Bloom's learning objectives was not conducted as part of this initial and limited study.

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