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Evaluating Flipped Classroom Strategies and Tools for Computer Engineering

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Introduction

A primary goal of engineering education is to provide students with requisite technical grounding along with practice and experience in the design and evaluation of real and practical systems. This goal becomes increasingly difficult with the expanding body of knowledge, integration of concepts across disciplines, and complexity of design tools needed in engineering industries. While an expert/apprentice model of education may be more fitting to preparing engineers for professional practice, traditional instruction models include in-person lectures covering fundamental technical concepts with the bulk of practice and application occurring outside of the classroom. This comes typically in the form of homework and labs (possibly in the presence of a teaching assistant) with delayed feedback from e-mail, office hour meetings, and occasional graded assignments. Little time is available in class for modeling and demonstration of the desired practice skills by the instructor and large class sizes often prohibit significant individual modeling, assessment or interaction with students.

As contemporary technology allows for pervasive access to multimedia content, educators have recognized the opportunities created for more personalized learning experiences and increased interaction and engagement with students. A "flipped" classroom is one term used to describe a pedagogical approach in which instructors reverse the traditional lecture (synchronous) versus homework (asynchronous) activities. A typical "flipping" involves moving *appropriate* lecture content to web-based videos that students watch before attending in class "lecture." In-class activities are then designed to answer questions or uncover common misconceptions, model the desired processes and skills an instructor intends for students to learn, and for students to practice those skills in an environment where they can receive immediate and helpful feedback.

The inverted[1] or flipped[2] classroom pedagogical approach was described more than a decade ago in an attempt to shift the role of the instructor from "sage" to "guide"[3] while allowing increased instructor-student interaction time and an increase in active-learning opportunities for students. A confluence of factors including technology, increased attention on STEM education, and market conditions have yielded a vast array of tools for capture and dissemination of educational content as well as automated and individualized formative and summative assessment. In turn this "flipped" classroom approach has found broad adoption in K-12 education and more recently in higher education institutions. However, in the context of STEM (Science, Technology, Math, & Engineering) education (and computer engineering, in particular) sparse literature exists on which strategies and tools are most effective in a "flipped" model nor the actual learning outcomes achieved by participants of this model. Of the available literature, a majority evaluates student perception in broad strokes with less focus on the component parts of the classroom flip or their effect on particular educational objectives or outcomes.

In this paper, we present the results of a three year study of a "flipped" classroom pedagogical approach in a traditional computer architecture course and detail the various strategies and tools used for both in- and out-of-class activities. We attempt a more fine-grained evaluation of the components techniques of the "flipped" approach as well as the new active learning techniques that are introduced during class meeting times. In addition, we explore how the "flipped" approach affects lower-order (remember, understand, apply) vs. higher-order (analyze, evaluate, create) learning outcomes as defined in Bloom's taxonomy[4]. Our stated research questions include:

- What are student perceptions of the effectiveness of the component techniques used in a “flipped” classroom approach?
- Which active learning techniques impact lower- vs. higher-order learning outcomes?
- How does student perception of the flipped classroom component techniques align with improved performance?

In this context our key contributions include:

- Results of our student perception questionnaire regarding the various “flipped” structures and active learning techniques were highly positive overall.
- Strategies and activities involving modeling and demonstration of skills were highly valued by students while some strategies aimed at students' metacognitive approach were lowly regarded.
- Evaluation of student performance on a variety of assessments indicate that student learning outcomes aligned to lower-order learning outcome have statistically insignificant differences between the "flipped" and traditional approaches, yet significant gains (up to 17 percentage points on a scale of 100) were found for outcomes aligned to higher-order learning outcomes.

Background and Review of Research

Because there are many interpretations and implementations of an "inverted" or "flipped" classroom, let us define the term "flipped" classroom as one where “events that have traditionally taken place inside first the classroom now take place outside the classroom and vice versa”[1]. The typical flipped classroom achieves knowledge transfer of fundamental conceptual material via reading assignments and video lectures which students are responsible for before attending the in-person lecture. This lecture then becomes a setting for questions, joint problem solving, and targeted discussion of topics that require more in-depth treatment as well as short, interactive learning experiences that provide individual and group practice along with immediate feedback.

By itself the "flipped" classroom is simply a format or approach to organizing a course’s time and structure. The real advantage of the inverted classroom is allowing and enabling active learning techniques to be introduced to a greater degree. Formally, active learning is defined as the involvement of students in their own learning.[5] Active learning techniques engage students in their learning process by allowing them to set appropriate individual learning goals, providing learning experiences in support of those goals, as well as providing immediate feedback that helps students assess the degree of their attainment of those goals. These active learning techniques can yield increased achievement of student learning outcomes and is the focus of much educational research[6]. Instructors no longer convey knowledge in a predominately one-way conversation, but become facilitators of educational experiences designed to help students master specific concepts or skills.

It is also important to note that the “flipped” classroom approach is not simply synonymous with distance learning or online education. Importantly, it promotes interaction as opposed to replacing it and thus can be considered a hybrid of traditional lecture approaches and fully online, distance learning approaches. Research indicates that this kind of hybrid approach that actually encourages interaction is superior to either alternative[7]. It is found to facilitate deeper learning and generalization of knowledge beyond individual courses.

Several previous works in the context of engineering education have been published. One of the first was the eTeach system.[8] Taking a typical "flipped" approach, this Matlab course used videotaped lectures (with synchronized slide presentations) to replace traditional lectures and live class periods were used for team-based problem solving. Applied to hundreds of students over several semesters, perceptual surveys indicated that over 66% of students believed that the "flipped" approach had a positive effect on their learning with 16% of the students indicating a negative effect. Of the team based problem solving occurring during class meeting time, 45% of students thought it yielded more interaction with the professor, while 31% actually thought it yielded less interaction. When compared to live lectures 57% of students agreed or strongly agreed that the "flipped" lecture was useful whereas only 36% gave similar ratings to the traditional approach. This case study of a course indicates students' value the flipped approach however no mention is made in this study of the impact of the "flipped" classroom on student learning.

Zappe, and colleagues[9] utilized a similar approach to eTeach. Their research focused on how students used video lectures and their perception of the approach. Again, student surveys were used to understand sentiment about the length of video lectures and their frequency of use. Approximately 88% of students indicated 20-30 minutes were the optimal length of a lecture video while roughly the same percentage indicated that they believed the "flipped" approach should only be used 25-50% of the time (i.e. a significant number of traditional, frontal lectures were still desired). Ultimately, this study also supports the recognition by students of the value of the "flipped" model and in this case, particularly the video portions of the pedagogy. However, once again no links to actual student performance were noted in this study.

Ronchetti[10] also describes a "flipped" approach for a C++ and Java object-oriented design and programming course in his research. Again, assessment in this study was geared towards understanding overall student perception of the technique with particular focus on student satisfaction with watching videos and its associated workload before class meetings. Ronchetti's results indicate that greater than 70% of the students responded favorably to use of the video lectures. In addition, approximately, 90% of students agreed or strongly agreed that the "flipped" approach allowed them to "get deeper into the presented concepts," "understand better in general," and "have better participation." These anecdotes indicate that the students in Rochetti's study viewed the flipped approach as linked to improved learning. Unfortunately, these comments were not supported by empirical evidence of that improvement.

Gannod, and colleagues[11] found that flipping the classroom forced them to move from several long homework assignments to shorter, more numerous assignments in their courses where the bulk of the work could be completed during the class meeting time. This was overwhelmingly welcomed by the students as indicated in their research. This finding was supported in similar research by Toto and Nguyen[12] in which they studied student satisfaction with the "flipped" model as it relates to student learning styles.

In all of the reviewed studies on flipped classroom pedagogical approaches to instruction, the dominant focus of analyses were on topics related to a "new" pre class meeting video lecture delivery format. The general consensus from this review was that students appreciated the flipped format with its increase in access and availability to lecture content but still enjoyed some frontal lectures during class meetings. In addition, there were generally increases in interaction. Some studies indicated that students perceived that their understanding is deepened by the "flipped" approach, however these claims were unfortunately not supported by empirical evidence of such improved understanding and learning of course content.

Importantly, much of the available literature indicates that when student performance on common assessment instruments is compared for both "flipped" and traditional pedagogical approaches, little difference is observed. Thomas and Philpot[13] developed a very large pool of videos and animations along with thousands of assessment questions in a mechanics of materials course. They assessed student performance in "flipped" and traditional course. While the assessment data yielded many interesting findings, these researchers noted that no significant difference existed in student performance on exams between the "flipped" and traditional classes. Similar limited of performance differentiation has been documented in a K-12 "flipped" classroom approach study.[14] This is of particular interest and importance because as previously described; students from the "flipped" approach perceive that their learning and understanding was deeper. Accordingly, exploration of this phenomenon begs further inquiry.

Other modifications of the typical "flipped" classroom approach are also documented besides video prelectures. Bland[15] took problem-based learning (PBL) approach to a flipped classroom, where students were presented with assignments before an upcoming class meeting that used concepts that had not been discussed prior. Students were expected to find and utilize available resources (textbook, web, peer-based learning, etc.) to complete the assignments. The goal for this pedagogical approach was to develop individual learning skills that would better prepare students for careers in industry where sparse guided assistance is available and more responsibility is on the learner to find, evaluate, and then integrate sources of knowledge. Students who experienced the PLB in Band's study indicated they better retained and understood the course material but did not necessarily prefer the approach compared to traditional lectures.

Regardless of the model of flipped classroom pedagogical approach, the reviewed research does not indicate improved learning resulting from the flipped approach. Importantly, in most studies, students' perceptions of the approaches were of primary foci. In our research we, too, explore student perceptions of the flipped approach. We combine various pedagogical approaches to our model (described below). Additionally, we attempt to link student perception to student achievement in our three-year study and present our results empirically herein.

Flipped Classroom Implementation

For our "flipped" approach, we chose a junior level undergraduate computer organization and architecture. This course included coverage of fundamental computer organization concepts including assembly language programming and instruction set architecture, memory hierarchy concepts and policies, processor organization, and structures of discussion and practice with embedded systems programming. While conceptual understanding and mastery of these topics was important, students in the traditional lecture-based approach often struggled when posed with their application in specific hardware and software design projects. Students' proficiency with tools, ability to evaluate design trade-offs and alternatives and ability to implement an efficient design were often superficial and underdeveloped. Accordingly, we hypothesized that a "flipped" classroom approach would enable an expert/apprentice approach building on socio-constructivist theory[16] to learning with the instructor demonstrating and modeling problem solving techniques and project design/analysis skills and then enabling students to do the same with improved instructor feedback and formative assessment.[17.]

To implement the "flip" we shifted traditional lecture-based content that was factual and conceptual in nature, which previously accounted for approximately half of typical lecture material to web-based lectures averaging 30-40 minutes in length. Through the inverted classroom, students were required to watch these video lectures before coming to class and to take a brief online assessment quiz associated with the online lecture content. The in-class time freed by these lecture videos was replaced by active learning experiences designed to enhance students' achievement of the higher learning outcomes as enumerated in Bloom's taxonomy and moreover, Anderson and Krathwohl's revisit of the learning taxonomy[4,17] where students develop the ability to analyze, evaluate, and create in an engineering context. This approach has been used for three semesters, thus far in spring 2010, 2011, and 2012.

As stated, a critical and under-studied research and pedagogical question when implementing an "flipped" classroom approach is which active learning techniques would best utilize the in-class time and help students achieve greater mastery of design skills without sacrificing conceptual understanding? To fully answer this question, pedagogical approaches must be grounded in sound learning theory[18,19] that includes a social constructivist approach that engages students in active learning. According to Mayer[20] learning is a social, active process in which knowledge and, in particular, higher order knowledge (per leaning taxonomies) is co-constructed amongst learners and mediated by experts using an apprenticeship or cognitive coaching approach. As such, our particular choice of "flipped" components enabled engaged learning in the classroom that was mediated and guided but not "directed" by the course instructor as the content and pedagogical expert.

To maintain and aid mastery of the conceptual material that was pushed to video modules, we felt it critical to provide additional formative assessment opportunities to help students gauge their own understanding and inform their metacognitive process throughout the experience. Thus, we implemented the following active learning approaches for outside of the classroom walls:

> <u>Online Lecture Assessments</u>: Whenever a video-based lecture was assigned, a brief, online, auto-scored, multiple-choice assessment (using Blackboard in our case) was provided to assess students' understanding of the concepts. This provided direct feedback to students regarding their own mastery as well as serving as a form of just-in-time (JIT) teaching to inform what the instructor might review or expand upon in lecture. In addition, these online quizzes had the added benefit of sparking questions from the students during lecture if they were unclear about a concept or question (i.e. got the answer wrong). Finally, to provide

greater motivation to watch and carefully digest the lecture videos content, online assessments were graded as pass/no-pass and counted toward a participation score in the overall course grade.

Online, multiple-attempt, instant feedback homework: Pre-"flip", the course used pen-paper based homework assignments that were given after a topic was presented (usually once per week), collected after another week, graded, and returned the following week (and sometimes never collected from the students if they were absent or disengaged). While solutions to homework were posted within a day or two after an assignment was due, there was still a long (and often open) feedback loop created by this approach. Students rarely went back to correct misconceptions and often solutions were not viewed until studying for an exam. To attempt to close this feedback loop for students, homework were moved to online Blackboard mini-exams. Where design-based or open-ended problems existed, they were converted to a closed-set of possible solutions from which the students would choose. Then, the test options were set so that students would be able to see which questions they answer correctly upon submission (though not the correct answer) and allow them to retake the exam as many times as desired. Immediately, it is clear that an issue results from this approach. Because questions were changed to closed-set, feedback on which questions are answered incorrectly, and unlimited attempts are allowed, a very motivated student may achieve a perfect score simply by guessing enough times. In spite of this potential dilemma, the online homework assessments' benefits outweighed their disadvantages (and if guessing was employed to achieve a perfect score, time invested to such efforts were often prohibitively high since answers were not auto saved from one attempt to the next and thus would required re-entering the entire solutions for each submission). The first benefit was that students received immediate feedback when they answer incorrectly, enabling the instructor to "auto-scaffold" students' learning and prompting students to correct their misconceptions. Second, even when guessing the correct answer, students were motivated to then understand why the answer they guessed was correct. To mitigate the disadvantage described above while still motivating the students to approach homework seriously, they were weighted only as 8-10% of the overall course grade.

Journals: Using Blackboard's online Journal feature (essentially a running blog between the instructor and student), students were obligated to provide feedback (for at least one out of every two video lectures) after watching online lectures. Aimed at jumpstarting the students metacognitive processes, they were asked to list questions they had, what they found interesting, and what topics warranted more review. Before coming to lecture, the instructor sampled the questions posed in these journal entries and used them to start each lecture with a discussion of the questions and their answers. Additionally, if a post warranted, a written response was provided which helped students to further engage.

With fundamental concepts and basic technical knowledge solidified in the out of class pedagogical approaches, we used a variety of active learning techniques in class to achieve higher order design and analysis skill in class, aligned with Anderson and Krathwohl's (revised Bloom's) learning taxonomy.[17]

Use of primary sources for learning: On several occasions, rather than providing summary or pre-canned lecture material, students were asked to use primary sources to find the answer to certain problems in class. For example, when learning the instruction set for our processor case study, students were asked to pair up and examine the manufacturer's online reference manuals to learn how an instruction worked and its proper usage then report back to the class. This type of exercise increases students' independent learning and builds confidence in their ability to find, understand, and integrate information from engineering documents.

Use of Tablet-PC with incomplete lecture notes: While much debate exists over the effectiveness of PowerPoint or other lecture slides, the courses described for our research used PowerPoint for a majority of lecture content (both in offline videos and content that continued to be covered in-class). However, rather than simply giving out lecture slides, students were given the opportunity to actively engage in lecture through the provision of incomplete PowerPoint slides (using a CLOZE type procedure[21] which includes missing important statements and half-worked examples or diagrams) to students before class. During lecture, a tablet-PC was employed where instructor and student could together complete the slides (i.e. the instructor completed the slides while students marked up their own printouts or used their own digital input devices). This approach has two effects. First, it engages students to think, write, and ponder the possible completions and solutions to the slides. Many instructors believe the act of writing enables certain mental processes that aid learning. Second, it slows the pace of content delivery and allows for important points to be highlighted and processed by students since they are not present in the provided slides. This allows the instructor to initiate discussions or solicit alternative thoughts and approaches from the class before providing the solution originally intended, enabling a guided experiential learning approach.[22]

Think alouds: In an effort to demonstrate and model the mental and cognitive processes that an expert might employ to decompose a large design problem or analyze possible approaches, the pedagogical practice of think-alouds were employed[23]. As their name suggests, the instructor took a proposed design problem and talked out his/her mental approach to it. For example, one project performed in our course is to write an assembly language floating point addition/subtraction emulation library. In this case, the instructor talked through his/her mental approach to the problem trying to decompose it into a series of smaller problems, considered implications of specific approaches, and consider the efficiency of a solution. At various points, student input was solicited or students placed into groups to come up with their own approach or solution to a particular problem. Doing this not only helps students get started on their own project but serves as an example for how one might approach future problems they encounter in real life situations., demonstrating problem solving as a higher order thinking process..

In-class project work: By moving content to video, more in-class face-to-face instructional time was available for projects and other group efforts. Students were often asked to perform pieces of their homework or projects in class where an instructor or TA could roam the classroom monitoring progress, answering questions or addressing issues synchronously rather than hours if not days after students encountered them.

Evaluative/Research Methodology

To assess the effectiveness of our particular "flipped" approach both in terms of student perception of impact and knowledge gains and to answer our research questions, we employed diverse evaluative approaches,.

To assess the students' perception of the effectiveness of the specific components of our "flipped" approach and the active-learning strategies, a cumulative student questionnaire was conducted of students from each of the three semesters (2010, 2011, and 2012) who experienced the "flipped" approach. With 111 respondents over all three semesters (see Table 1) questions were posed regarding each of the component learning approaches of both pre-class and in-class meeting times. Both closed set and open-ended questions were used for this perceptual questionnaire.

Year	2010	2011	2012
Participants	37	32	42

Table 1- Student Survey Respondents

To address our research question regarding lower- vs. higher-order learning outcomes, we introduced assessment strategies to measure both kinds of learning goals. To measure the lower-order learning outcomes, we used a concept inventory that had been in place for several semesters prior to the "flip" so that we could compare data across semesters. We also used a common final exam for each semester. These two knowledge measures were implemented both for students who experienced the flipped classroom pedagogical approach and the traditional approach so that comparisons could be made in terms of achievement that may have resulted from the "flipped" approach.

To measure the higher-order outcomes resulting from the "flipped" approach, we used two primary project assignments: 1.) writing an assembly language library to emulate IEEE 754 floating point addition/subtraction along with unit tests and driver (testbench) program, and 2.) a Verilog (hardware description language) design of a multi-cycle CPU implementing a subset of the MIPS processor instruction set as the primary assessment instruments of our approach with open-ended choices in additional instruction support. Rubrics were developed and used for each project to ensure consistent, empirically based grading from student to student and semester to semester. A major component of scoring on each rubric was *automated* testing and scoring of the students' design, so that human biases would be less pronounced. Each assessment was initially run in spring 2009 before the "flipped" approach was implemented and then again in spring 2010, 2011, and 2012 when the "flipped" approach was used so that we could compare results between traditional course delivery and a flipped pedagogical approach with the same course content and the same course instructor.

Results and Discussion

To answer our first research question associated with student perception of the effectiveness of the flipped classroom components we present the results of the student cumulative questionnaire as follows. Figure 1 indicates students' rating of the effectiveness of the component activities used in the "flipped" approach using a 7-point Likert-type scale (1=Very Ineffective and 7=Very effective)

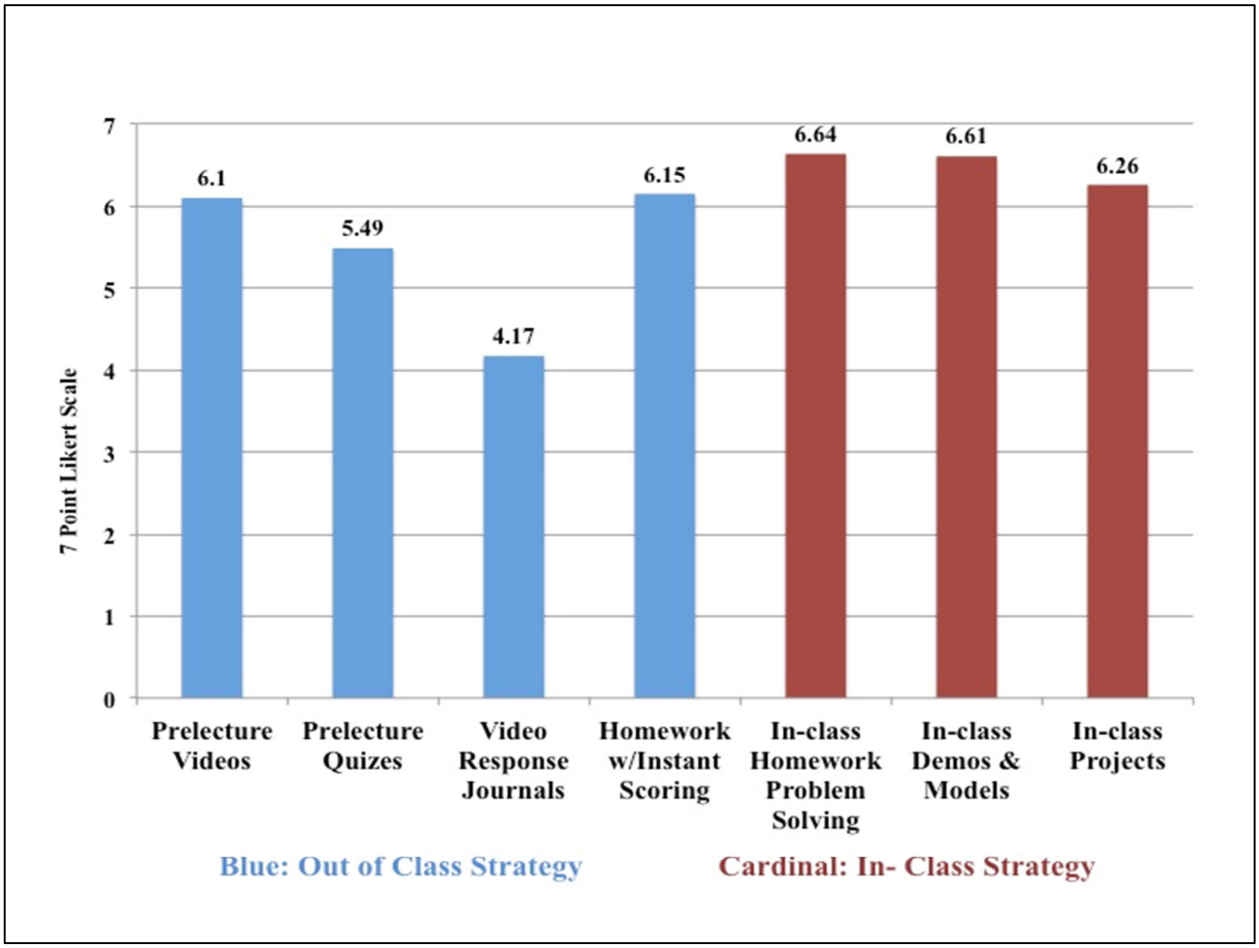

Figure 1 - Student Ratings of the Effectiveness of Various Techniques used in the "Flipped"

Prelecture work (videos and assessment quizzes) was rated as effective (average mean = 5.48) but to a lesser degree than the in-class activities which scored very highly (average mean = 6.50). The journal assignments were rated lowest by students (M=4.17) while in class problem solving was rated highest by the students (M = 6.64) . The most cited reason that the videos were ineffective is their length (average of 40 minutes). In summary, the students preferred more frequent , shorter videos. However, students indicated that the added problem-solving and modeling in class made up for the prelecture videos and that these activities were the most effective components of the classroom "flip."

Figure 2 (below) illustrates the results of student attitude and perceptions regarding the pre-lecture videos versus in-class activities. Using a 5-point Likert-type scale (1 = Strongly Disagree / 5 = Strongly Agree) students were asked about the value, depth of understanding, and enjoyment of both the video lectures and in-class activities.

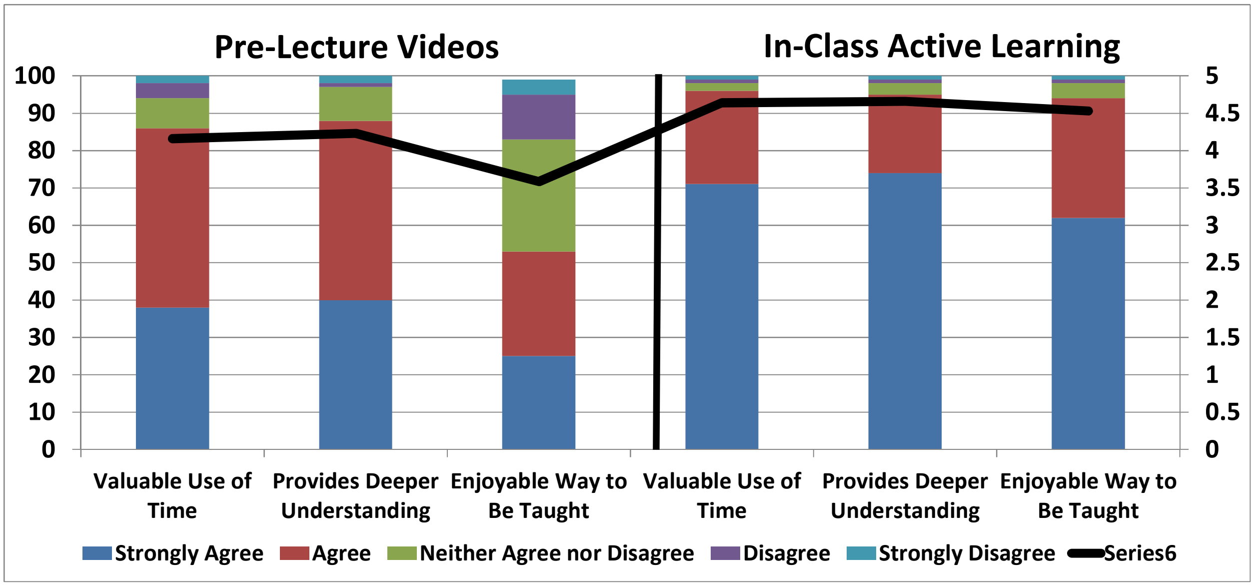

Figure 2 - Student Perception of the value, depth of understanding, and enjoyment of both prelecture videos and in-class active learning techniques. NOTE: The mean of the 5-point Likert-type scale is plotted on the right vertical axis.

Similar to previously cited research, our students indicated appreciation of the value of the videos (M= 4.16) but did not find watching the videos particularly enjoyable (M= 3.58). Given that our goal was not necessarily to entertain the students, we viewed their valuing of the video as important to our research.

As previously described, we also asked students to provide open-ended feedback associated with their view of the successes and challenges of the "flipped" classroom. We analyzed these open-ended responses using well-established thematically focused qualitative analyses. Specifically, data for the open-ended responses was coded and thematically categorized using a constant, comparative method[24]. Special attention was paid to disconfirming evidence and outliers in data coding, as well as elements of frequency, extensiveness, and intensity within the data. Ideas or phenomena was initially identified and flagged to generate a listing of internally consistent, discrete categories, followed by fractured and reassembled (axial coding) of categories by making connections between categories and subcategories to reflect emerging themes and patterns (represented in Table 2). Categories were then integrated to form grounded theory using selective categorization to clarify concepts and to allow for response interpretations, and conclusions associated with the students' perceptions of success of the "flipped" classroom. Frequency distribution of the coded and categorized data was obtained (see Table 2). The intent of this intensive qualitative analysis was to identify patterns, make comparisons, and contrast one person's feedback in the student questionnaire with another. Interpretation of the data follows and is described and preliminarily aligned with relevant literature presented in the beginning of this paper.

Themes that resulted from this analyses include: interaction between student and instructor, class preparation, knowledge gained, student engagement, modeling and problem solving, and time commitment. A total of 49 responses were recorded. Many of the student responses were multidimensional and therefore were coded under various themes. Table 2 below represents a frequency distribution of the themes established through the qualitative analyses of the data. Examples of each theme are included in the table.

Theme	Frequency (Percent)	Response Examples
Interaction: Student-Instructor	7 (10.1)	"Passiveness that is usually found during lecture time is traded for an interactive time with the professor and other students."
Class Preparation	16 (23.2)	"Felt much more prepared for classes. Also, because the Professor would review the material in the pre-lecture videos, I didn't feel like I had to teach myself the material as I have when other teachers have wanted me to watch online lecture videos."
Knowledge Gained	13 (18.8)	"It worked extremely well as far as helping me understand difficult concepts."
Engagement	11 (15.9)	"The "inverted classroom" approach requires much more involvement from students."
Modeling/Problem Solving	5 (7.2)	"it added a valuable experience through the projects. I learned a lot more than I would have with just normal lectures and I got some hands on experience which is always greatly appreciated in engineering classes since they help you relate to industry."
Time commitment	17 (24.6)	"I just think some of the videos were too long (should be ~20 minutes when possible instead of 45 min long). Also, the earlier the videos are available, the better, since finding time to watch a long video like that the day before class is sometimes difficult."
TOTAL	69 (100%)	

Table 2- Thematic Representation of Student Perceptions of "Flipped" Pedagogical Approach

The examples provided in Table 2 are but a few of the many rich examples of the value that students placed on the inverted classroom as a sound pedagogical approach in engineering education. Importantly, the students' open-ended comments are directly aligned with the theoretical approaches that we utilized to design and implement the course. In an open-ended response, one student stated,
"Since most of the learning for students happens during the homework process, the guidance available to the student in the classroom allows for correction of mistakes, collaboration with fellow peers, and an all-around richer experience."

While this student was unaware of our theoretical rationale for the manner in which we structured the course, he was right on the mark with regard to the benefits that come from guided experiential learning[22] and social constructivist approaches to learning.[16]

An additional example of such theoretical alignment came from the following students' comment:

"It was really nice to learn the basics of a concept on my own at my own pace and have the opportunity to ask more in depth questions during class. Class time wasn't wasted on the basic understanding of concepts."

This student clearly recognized that developing deep understanding of difficult skills and application of concepts is important. This comment represents an appreciation of the importance of developing higher order knowledge dimension as represented in Anderson and Krathwohl[17].

In terms of student perceptions, summarily, modeling and demonstration was listed as just as important as problem-solving indicating the uncovering the process of solving and analyzing problems or designing solutions was just as valuable to students as working on homework problems and engaging with engineering examples. Similarly closing the loop on homework assignments by making them auto-graded, multiple attempt assessments was also very much appreciated by the students. The least effective approach from the students' perspective was the use of journals that attempted to have students reflect on their learning and create a back-and-forth conversation between the instructor and student. Anecdotal evidence from discussions with the students was that obligating journal entries felt burdensome and students wanted the least amount of work as possible before coming to class. In addition, the sheer size of the class made it difficult for the instructor to respond to each individual entry and thus it was perceived as having less value.

In addition to measuring student perceptions of the impact of the "flipped" approach, , we focused our attention to answering our final two research questions associated with the impact of the increased active-learning techniques in the "flipped" pedagogical approach on the lower-order and higher-order learning outcomes. As described, previous research in higher education and K-12 has indicated little to no gain in student achievement associated with the "flipped" approach. In our research, we attempted to explore this phenomenon further and specifically to carefully parse out results in terms of achievement of both higher and lower order skills given that we followed Anderson and Krathwohl's theoretical approach to improving and measuring learning [17] We noted through review of the literature previously described in this paper that research focused primarily of student perceptions of effectiveness of the Flipped approach and lower order thinking. While we did not ignore these two factors in or research we added higher order knowledge dimensions to our research design. Previous research that explored knowledge impact used instruments that pertain to the lower-order learning outcomes (i.e. concept inventories, multiple choice final exams, etc.). Likewise, results from our concept inventory and final exams show similarly insignificant differences in student performance between the "flipped" and traditional approaches. Figure 3 represents the comparative performance of students on a course specific concept inventory for both the baseline (control) semester in 2009 and the three semesters using the "flipped" pedagogical approach.

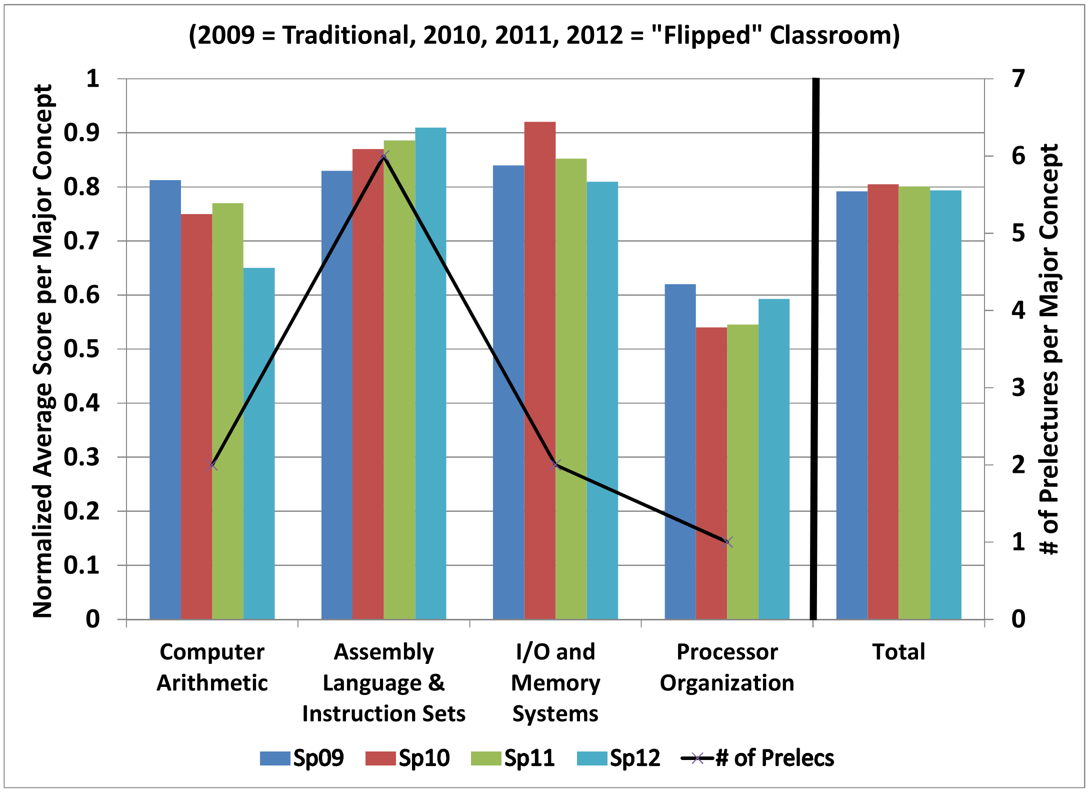

Figure 3 – Student Performance on the different topics of the concept inventory followed by the overall average. The number of prelecture videos and assessments used for each topic are plotted on the right vertical axis.

The total average performance is nearly identical across all semesters indicating that the "flipped" approach yielded little gain in cumulative student performance on conceptual questions. The final exam results also corroborate this conclusion, as most of the final exam addresses lower-order learning outcomes.

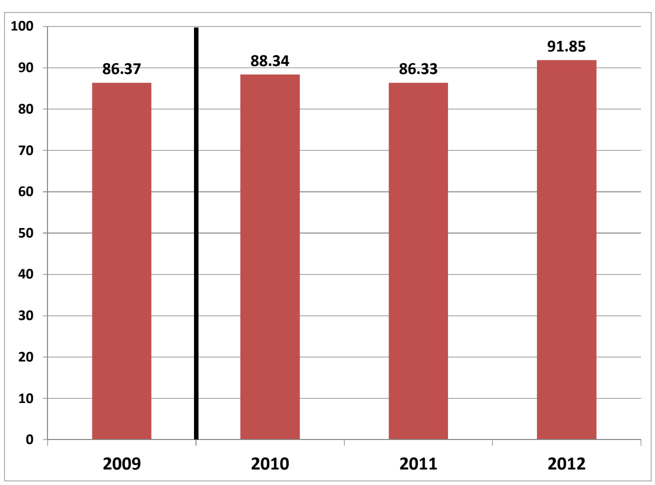

Figure 4 – Average final exam scores for the "traditional" approach in 2009 and "flipped" approach in subsequent semesters.

However, one point is observed when the performance on the concept inventory topics is correlated with the frequency of using a "flipped" approach. The assembly language topics used six prelecture videos and assessments while other topics used only one or two. Interestingly, this is the only topic that has seen increased performance over each year. Going back several years Figure 5 plots the normalized performance on the assembly language topics. While a firm conclusion cannot be drawn from this data alone, it does suggest that the increase in ownership and engagement resulting from a "flipped" approach provides some improvement in lower-order learning outcomes.

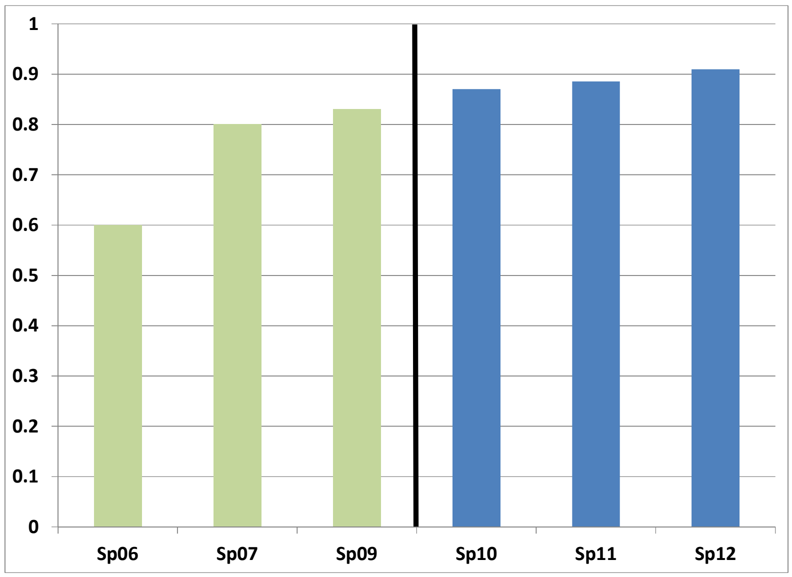

Figure 5 – Performance on the assembly language concepts for three "traditional" semesters and three "flipped" semesters.

In summary, in terms of lower order learning, our research is congruent with the results of others that a "flipped" approach does not necessarily improve student performance for lower-order learning outcomes. At that same time, a "flipped" approach does not decrease performance for these outcomes either, suggesting it is a viable alternative to a traditional model.

We now turn our attention to the impact of the flipped classroom on higher-order learning outcomes. Our original hypothesis in designing our "flip" was increased class time and student-instructor interaction afforded by the "flipped" approach would produce an increase in students' higher-order learning outcomes (analyze, evaluate, create). Accordingly, we used the course projects to measure these outcomes since they require students to exercise their own design and analysis skills and the approach and implementation are left open-ended. Figure 6 (below) illustrates the average student scores.

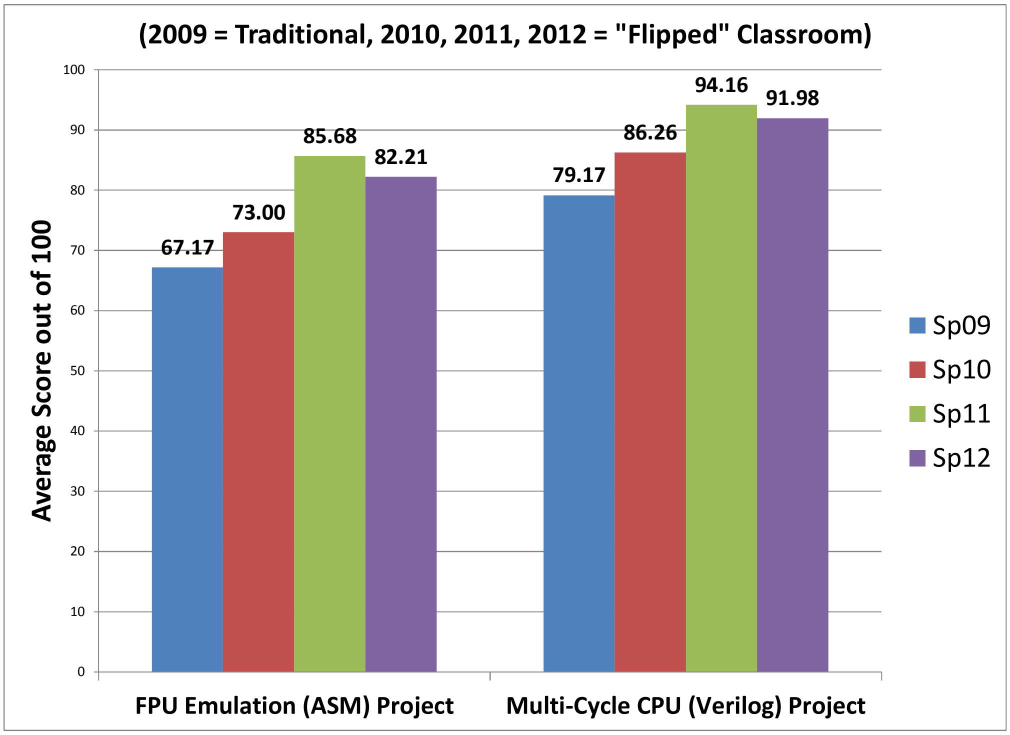

Figure 6 – Performance on the two projects of the course for the traditional and "flipped" approaches.

We see significant gains were achieved over the traditional approach used in spring 2009 for all cases. An interesting gain in performance occurs between the first (2010) and second (2011) year of the "flipped" approach. The first time using the "flipped" approach was used the instructor neglected to utilize modeling and demonstration techniques (e.g. think-aloud, think-pair-share, etc.) while the spring 2011 projects included a think-aloud for decomposing the designs. Averaging over the three semesters where a "flipped" approach was used a 13-point and 11-point increase in performance is attained. For all projects, class time was provided for students to work on their designs in the presence of the instructor.

We contend that the primary advantage of the "flipped" approach is not in the lower-order learning outcomes but in the higher. Speaking in terms of just student performance, traditional lectures and lecture videos are equally good at conveying conceptual and factual knowledge and over the timespan of a semester or quarter homework and other activities tend to normalize student performance whether a traditional or "flipped" approach is used. However, the "flipped" approach's advantages are seen most clearly and are most useful when attempting to instill high-order learning behaviors and outcomes in students. These skills are those most desired by industry leadership.[23] Increased time for modeling, interaction, and feedback all support higher achievement. They are also valued by our students as indicated by the results of our students' perceptual questionnaire. As such, students' perceptions of the impact of the "flipped" approach are in direct alignment with the empirical gains in higher order skills that students had. This lends further credibility both to our research approach and to the specific pedagogical components that we employed in our "flipped" classroom approach.

Conclusion

In conclusion, we outline several pedagogical components that are useful in the context of a "flipped" classroom approach and evaluate their usefulness from student perspectives. While videos are appreciated, the real advantage that students recognized is increase problem solving and modeling of skills that can be afforded by the "flipped" approach. It may be that future efforts should focus more on the specific active-learning techniques that can be used in place of traditional lectures, rather than on how best create the offline lecture content. We further demonstrate that the advantages of a "flipped" approach are not found in the conceptual and factual knowledge gained by students but in the increased time used for active-learning techniques which can help student achievement of higher-order learning outcomes, seen by the increased performance for the course projects.

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