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Comparing the Effectiveness of Blended, Semi-Flipped, and Flipped Formats in an Engineering Numerical Methods Course

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ABSTRACT

Blended, flipped, and semi-flipped instructional approaches were used in various sections of a numerical methods course for undergraduate mechanical engineers. During the spring of 2014, a blended approach was used; in the summer of 2014, a combination of blended and flipped instruction was used to deliver a semi-flipped course; and in the fall of 2014, a fully-flipped approach was taken. Blended instruction aims to integrate technology-driven instruction with face-to-face learning and is often used to enhance the traditional lecture. With "flipped" instruction, students practice skills during class after viewing or/and reading lecture content beforehand. To directly assess these instructional methods, we compared multiple-choice and free response results from identical final exams. We did this for all students as well as demographic segments of interest to our research, including underrepresented minorities and transfer students. We uncovered several differences having medium to large effect sizes, suggesting that some degree of flipped instruction may have been more beneficial than blended learning for both lower and higher-order skills development. The students rated the classroom environment using Fraser's College and University Classroom Environment Inventory (CUCEI). The three classroom environments were statistically similar with small effect sizes. However, there was a trend in lower ratings for the flipped and semi-flipped classrooms versus the blended classroom across the various environmental dimensions. This may indicate that blended instruction had the most desirable classroom environment. Based on an evaluation survey, only 38% of respondents preferred flipped instruction to usual methods, although 54% preferred active learning to lecture. In an open-ended question, the most frequently-stated benefits of flipped instruction involved enhanced learning or learning processes, and engagement and professional behaviors. These results aligned with our focus group results. This study is believed to be one of the first to compare these three modalities in a STEM course.

Key words: Flipped class, Blended instruction, Numerical Methods, Mechanical Engineering.

INTRODUCTION

The teaching of STEM courses solely through the traditional lecture is emerging as an ineffective and inferior method of instruction (Mazur, 2009; Freeman et al., 2014; Wieman, 2014). When topics are complex, students require in-depth engagement activities to practice their higher order thinking skills and fully construct an understanding of the topic (Garrison & Vaughan, 2008). Blended learning has emerged in higher education as a means to provide more engaging, quality-driven experiences for learners. It aims to optimally integrate face-to-face teaching with online learning (Garrison & Vaughan, 2008; Bourne et. al, 2005; Dziuban et al., 2006). With blended learning, aspects of face-to-face classroom learning are replaced or enhanced by online or technology-based experiences, such as simulations, labs, tutorials, and assessments (Garrison & Vaughan, 2008). Those who employ blended learning have the objective of "using the web for what it does best, and using class time for what it does best" (Osguthorpe & Graham, 2003, 227). Thus, blended learning is the convergence of two historically separated teaching models – traditional face-to-face and more recent computer-mediated models, which often aim to accommodate collaborative human interaction in the form of virtual communities (Graham, 2006). A related approach, the flipped classroom, has also emerged in higher education. This approach frees class time for higher-engagement activities such as problem solving. This is typically accomplished by having students watch online videos with lecture content before class (Bergmann & Sams, 2012). Thus, with "flipped" instruction, students apply skills during class after preparing with lecture content beforehand, and instructors serve in a support role as guide and coach during this skills application (Velegol et al., 2015).

Studies have shown that active or interactive learners achieve significantly better results and gains compared to passive learners in problem solving, time to mastery, and conceptual understanding (Chi, 2009; Hake, 2001). A recent meta-analysis of studies comparing active learning to traditional lecturing indicated that student test performance increased by about half a standard deviation on average in active-learning STEM courses. Also, average failure rates were 22% with active learning compared to 34% with traditional lecturing (Freeman et al., 2014). In addition, educators have stressed that genuine learning occurs when students discuss, analyze, apply, problem solve, design, and otherwise perform active learning (Prince, 2004; Bonwell & Eison, 1991).

An NSF grant entitled "Improving and Assessing Student Learning in an Inverted STEM Classroom Setting" allowed us to compare active learning methods, specifically blended, flipped, and semi-flipped instruction, in a numerical methods course at the University of South Florida (USF) over the course of three semesters (Kaw et.al., 2013). This required class is taken by junior and senior mechanical engineering students and covers numerical methods for differentiation, nonlinear equations, simultaneous linear equations, interpolation, regression, integration, and ordinary differential equations. We began a formal comparison of blended instruction vs. flipped instruction vs. a combination of the two in the 2014 spring semester. This is one of the first studies we are aware of that compares these three methods in a STEM course.

The spring 2014 course was taught in a blended fashion and consisted of in-class lectures, clicker questions, and exercises. In addition, there was an online discussion board, lecture videos, and online quizzes. This course aligned with the *supplemental* model of blended instruction, which retains the structure of the traditional class but adds technology-based activities outside of class to enhance student engagement and offer additional resources (Twigg, 2003). The instructor had extensive prior experience in teaching this course in a blended manner. "Mixing it up" in the summer term, half of the topics were taught in a blended mode and the other half in a flipped mode. In the flipped sessions, students watched video lectures and/or read the textbook before class. During class, students worked in teams on exercises or applications and used clickers. Micro-lectures were employed as necessary, and the online discussion board was also available. In the fall term, the course was fully flipped using these same resources.

In investigating and comparing these instructional methods, our research questions were as follows:

1. Is there a difference in numerical methods achievement level, in particular for various student demographic groups, when using blended, flipped, and semi-flipped instructional approaches?
2. Are there differences in students' perceptions of the learning environment within blended, flipped, and semi-flipped numerical methods classrooms?
3. What are the benefits and drawbacks of flipped instruction in numerical methods based upon the students' perspectives?

By investigating these research questions, we aim to develop recommended practices for teaching numerical methods using technology-enhanced and/or active-learning approaches. Our objective is to inform faculty who are interested in using these types of teaching and learning approaches for numerical methods and other engineering courses. The lessons learned have the potential to change the way numerical methods and other engineering courses are taught.

Therefore, in the following sections, we further review the existing literature on blended and flipped classrooms, including for mechanical engineering courses and courses directly related to numerical methods. We then discuss our methods, including course delivery using each of the three modalities as well as our data collection and statistical analysis methods. This is followed by a detailed comparison of the multiple-choice and free-response exam results for these instructional approaches, including for various demographic segments of interest as well as for various numerical-methods topic areas. We also provide a comparison of the three methods in terms of the classroom environment, and we present students' evaluations and perceptions of the benefits and drawbacks of the flipped classroom as gathered through a survey and focus group.

LITERATURE REVIEW

Blended and Flipped Classrooms: Descriptions and Motivations from the Literature

A major initiative with blended learning was an instructional redesign program that encouraged higher educational institutions to redesign their instruction using technology. Supported by the Pew Charitable Trusts, some of the improvement techniques included computer-based assessments and feedback, online student discussion groups and learning communities, computer-lab group work with faculty present in lieu of a lecture, and online interactive tutorials with assessment checks (Twigg, 2003). The University of Central Florida (UCF) has been a large adopter of the blended learning model and is a recognized leader in this area, having offered blended courses since 1997 (Dziuban et al., 2006; Cavanagh, 2011). The goals of blended learning have been identified as follows: pedagogical richness (to include enhanced or deeper student learning), student access to knowledge, social interaction in-class and online, student self-directedness and learning choices, cost effectiveness, and flexible and responsive learning atmospheres (Osguthorpe & Graham, 2003). There is evidence that blended learning can be more effective than a traditional instructional approach (Garrison & Kanuka, 2004).

Blended learning has been advocated or implemented in other mechanical engineering courses besides numerical methods, in which online experiments, web-based simulations, or remote labs have been used (Cortizo et al., 2010; Restivo et al., 2009; Henning et al., 2007; Hu & Zhang, 2010). Blended learning has also been used in courses that are foundational to numerical methods, such as introductory computer programming. In a large, first-year introductory computing course for engineers, an online, self-practice tool was put in place to provide an additional, flexible learning resource for students, in which they could assess their understanding, receive automatic feedback, and subsequently seek one-on-one assistance from instructors as needed (El-Zein et al., 2009).

Despite his long-time use of blended instruction in this course, the instructor developed an interest in flipping the course. The flipped classroom enables face-to-face time for application of skills with the instructor present for support. The instructor's primary goals were to promote higher order thinking and metacognitive skills. In addition, he wanted to drive student responsibility for learning, albeit using fully guided instruction (Clark et al., 2012). Similarly, in a very recent survey taken by almost 1,100 faculty members primarily from the US and Canada, the top motivations for flipped classrooms included increasing student engagement (79%) and improving student learning (76%) (Bart, 2015). In a second recent survey by the National Center for Case Study Teaching in Science, case-study teachers indicated that they teach in a flipped manner to increase interaction with students, promote flexibility, and increase student involvement in and engagement with their learning (Herreid & Schiller, 2013). This is in agreement with other sources that describe flipped instruction as increasing student-to-teacher interaction and student collaboration as well as providing self-paced "pause and rewind" capability and other benefits (Bergmann & Sams, 2012; Rosenberg, 2013).

In the discipline of numerical methods, a controlled study of the flipped classroom for a numerical methods course for engineers was recently done at Utah State University. A treatment section (i.e., flipped) as well as a comparison section (i.e., traditional lecture) were run concurrently (Bishop & Verleger, 2013; Bishop, 2013). The flipped section made use of multiple resources developed as part of the Holistic Numerical Methods initiative (HNM, 2015), shown in Figure 1, in addition to other previous work by Kaw and colleagues, including video lectures, and a concept test (Kaw & Yalcin, 2012; Kaw et al., 2012). Kaw and Hess previously investigated the effectiveness of the following four instructional delivery modalities for a single numerical methods topic area (i.e., nonlinear equations): 1) traditional lecture, 2) web-enhanced lecture, 3) web-based self-study, and 4) web-based self-study and classroom discussion (i.e., flipped mode). The last modality was found to be best for student performance, and the second was best for student satisfaction (Kaw & Hess, 2007).

The flipped classroom has been implemented with other mechanical engineering courses as well, including introductory mechanical design, statics and mechanics, and electronics instrumentation, as discussed in the literature (Dollár & Steif, 2009; Steif & Dollár, 2012; Cavalli et al., 2014; Connor et al., 2014; Papadopoulos & Roman, 2010). Online statics materials developed as part of the Carnegie Mellon Open Learning Initiative (OLI) have been used in both a flipped and blended fashion (Dollár & Steif, 2009; Steif & Dollár, 2012; Steif & Dollár, 2009). The flipped classroom is also being implemented in math courses such as calculus and linear algebra, which provide foundational knowledge for numerical methods (McGivney-Burelle & Xue, 2013; Talbert, 2014; Love et al., 2014).

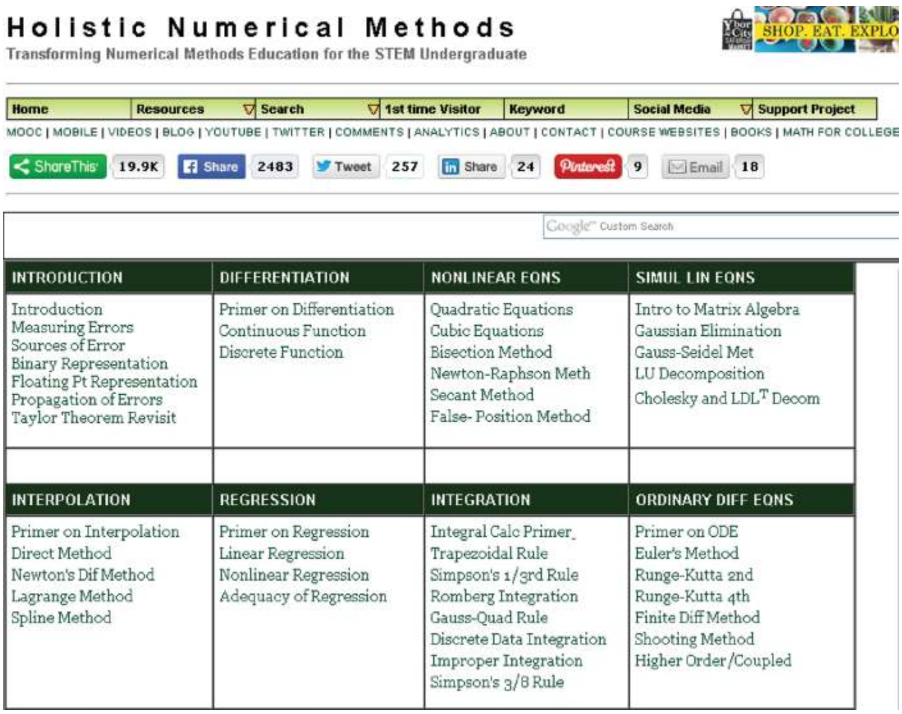

Figure 1. Holistic Numerical Methods Courseware (http://nm.MathForCollege.com)

Blended and Flipped Classrooms: Results from the Literature

In comparisons of blended versus traditional learning, blended learning has shown success. In the first round of the Pew Trusts' instructional redesign projects, which involved a range of arts and sciences courses, five of the ten projects reported improved learning outcomes. Four reported equivalent achievement, and one was inconclusive. The improved learning outcomes included significantly higher grades and exam performances. In addition, seven of the ten redesigns showed an improvement in course completion and retention rates, including decreased D/F/drop/withdrawal rates (Twigg, 2003). Assessment of face-to-face vs. fully online vs. blended courses at UCF has shown blended learning to have the highest level of student success, as defined by the percent of students earning a C or better. Blended courses also had the lowest withdrawal rate and the largest percentage of "excellent" ratings by students on the course evaluations (Cavanagh, 2011).

In mechanical and other engineering courses, student perceptions of blended learning have been favorable also. In a laboratory course that used a remote experiment for measuring mechanical properties, the students evaluated the impact of the remote lab. On a scale of 1 to 7, the students rated "deeper learning of previous knowledge" with an average value of 5.6 and "e-learning contribution for better learning quality" at 5.7 (Restivo et al., 2009). In the introductory programming course discussed previously, 75% of student respondents found the self-practice tool to be useful or very useful. In addition, the overall student satisfaction with the quality of the course rose 23% after implementation of the online tool (El-Zein et al., 2009). A group of 21 graduate engineering courses was taught in a traditional fashion and subsequently in a blended fashion to measure differences between the methods in terms of student satisfaction, class attendance, motivation, and collaboration. Survey responses from approximately 800 students were collected, and students perceived statistically greater levels of satisfaction, motivation, and collaboration with their classmates in the blended environment. Students also reported statistically higher attendance rates in the blended classrooms and identified access to their instructor as the strongest predictor of satisfaction with blended learning (Martínez-Caro & Campuzano-Bolarín, 2011).

With flipped instruction, comparisons to traditional instruction for other mechanical engineering courses have shown mixed results, both in terms of direct and indirect assessments. For example, at the University of Puerto Rico, an inverted classroom was implemented for several sections of a statics course (Papadopoulos & Roman, 2010). On an end-of-course Concept Assessment Tool in Statics (CATS), students in the inverted sections scored statistically higher than students in the traditional sections (p=0.0076). At the University of North Dakota (UND), where a series of undergraduate mechanical engineering courses was flipped, students in a traditional section of a numerical methods course exhibited a higher level of achievement compared to students in a flipped section. In the traditional section, 82% earned a C or better, compared to 72% in the flipped section (Cavalli et al., 2014). The controlled study for the numerical methods course at Utah State examined students' problem solving on usual assessments (i.e., homework and exams) as well as their understanding via a concept test developed by Kaw and colleagues (Kaw & Yalcin, 2012) and concept-based quizzes. The exam and quiz averages and the concept test gains were statistically equivalent between the treatment and comparison sections. Although average homework scores were statistically lower for the treatment section, it was believed that these students had a larger workload and had to prioritize other tasks over the homework assignments, which were worth a relatively small portion of the grade (Bishop, 2013).

In courses related to numerical methods or other engineering courses, the results have also been mixed. In a linear algebra course, students in the flipped section performed similarly to students in the traditional section on the final exam focused on conceptual understanding (Love et al., 2014). However, in a calculus course, students who received flipped instruction on certain topics, versus those who did not, scored four to five points higher on an exam and assignments that covered the topics (McGivney-Burelle & Xue, 2013). We did not uncover articles in our literature search discussing an approach similar to our semi-flipped approach, in which half of the course had been flipped and the other half had been run in blended mode. Rather, we uncovered studies such as the calculus study, in which one or a few units had been flipped within an otherwise traditionally-run course. In an environmental engineering course at Penn State, there was no statistical difference in the final exam scores across six semesters in which the course had been taught both traditionally and in flipped mode (Velegol et al., 2015). Interestingly, in the recent faculty survey discussed previously, although 75% of faculty saw greater student engagement with the flipped classroom, only one-half (55%) noted evidence of improved student learning (Bart, 2015).

In terms of student perceptions of and preferences for the flipped classroom, results have also been mixed, as noted previously (Bishop & Verleger, 2013). Fifty-four percent (54%) of the UND learners in the flipped sections preferred the flipped format (Cavalli et al., 2014). As will be discussed in the results section, this was higher than our percentage of students who preferred the flipped format for numerical methods. Similarly, in a flipped electronics instrumentation course taken by mechanical engineers at Rensselaer, 56% indicated a preference for online video lectures versus traditional lectures (Connor, 2014). In a comparison of student opinions of the learning experience in the Utah State study, the ratings were statistically equivalent between the treatment and comparison sections except for three items on the 18-item survey. These three items included learning to apply course material and an overall rating of the course. They were rated statistically lower by the treatment section and had medium effect sizes.

METHODS

To assess and compare the outcomes of the three methods for delivering numerical methods instruction, we developed a comprehensive plan consisting of direct and indirect assessments. We used final exam scores to directly assess and compare achievement with blended versus semi-flipped versus flipped instruction in numerical methods. The assessment analyst also conducted interviews and discussions with the instructor to uncover gains that may not have been apparent in the exam data. A student demographics survey was administered so the exam results could be analyzed for specific segments of the population, such as females, underrepresented minority students, or transfers to the college of engineering. In addition, the students were indirectly assessed for their perceptions using classroom environment and flipped classroom evaluation surveys. Finally, student focus groups were conducted with different demographic segments to assess benefits and drawbacks of flipped instruction. We will first discuss the methods used to develop and deliver the course and the participants in the three modes.

Course Delivery Methods and Student Participants

In the blended version of the course, students were assigned to view primers for the pre-requisite course material and take an auto-graded, online quiz prior to class. For the topics covered in class, an auto-graded, online quiz was assigned after class and due four hours before the next class. These quizzes consisted of about 90% algorithmic questions and 10% multiple-choice questions and were administered through the university learning management system, counting for 15% of the student's grade. The algorithmic feature enabled the same question to be presented to all students, but with random numerical parameters, thereby reducing opportunities for academic dishonesty. During class, lecture occurred, and clickers were used frequently (i.e., in approximately half of the class sessions) with peer interaction followed by instructor discussion. The clickers were used formatively, and a grade was not assigned to the responses. The students also worked on short exercises, assisting one another as needed. Some of these exercises were assigned as homework to be completed for a grade. The Piazza online discussion board was available continuously (i.e., 24/7) for very quick feedback from the instructor, TA and fellow students, as were the video lectures (Piazza, 2015). A summary of the teaching methods is given in Table 1.

Activity	Blended	Flipped
Pre-class	Study pre-requisite material via videos for one-half of the course topics. 24/7 access to open courseware & Piazza discussion board.	Study topic via textbook or video lectures. 24/7 access to open courseware & Piazza discussion board. Automatically graded quiz (due 3 hours before class). Essay question on most difficult or interesting concept from videos (due 3 hours before class).
In-class	Clicker quiz in half of class sessions to gauge conceptual understanding (not graded). Fewer questions presented vs. in flipped class. Questions answered correctly by fewer than 75% are discussed peer-to-peer followed by re-polling. Mostly lecture with active learning components (e.g., two-way questioning, clickers, short exercises with peer interaction); some graded.	Clicker quiz in every class session to gauge conceptual understanding (not graded). Questions answered correctly by fewer than 75% are discussed peer-to-peer followed by re-polling. Micro-lectures based on pre-class quiz and responses to essay question. Short exercises or outline-the-solution problems with peer interaction and instructor help; some graded.
Post-class	Automatically-graded quizzes (due before next class). Problem set of ~6 questions; not graded. 2-3 graded programming projects analyzing experimental data. Some in-class exercises assigned as homework; some graded.	Automatically-graded quizzes (due before next class). Problem set of ~6 questions; not graded. 2-3 graded programming projects analyzing experimental data.

Note: In the semi-flipped class, approximately half of the class sessions were blended, and the others were flipped.

Table 1. Comparison of Blended and Flipped Delivery Methods.

In the flipped version of the course, students were assigned to watch lecture videos and/or study the textbook before class. In addition, an auto-graded online quiz and an open-ended question were due four hours before class. The open-ended question prompted the student for the most difficult or interesting topics encountered in the videos. These were read by the instructor prior to class, and most of them were addressed during class through micro-lectures. Others were addressed via the Piazza discussion board, using established links and blogs, text, and PDF files with worked examples. Clickers were used almost daily. Students completed exercises or outlined solutions to an applied problem with their peers. Auto-graded, online quizzes were assigned after class on the topics covered in class. The quizzes again counted for 15% of the student's grade. A presentation showcasing how the flipped class was taught can be accessed at http://www.eng.usf.edu/~kaw/flipped/autar_kaw_flipped_classroom_workshop_2015.pptx.

In the semi-flipped version of the course, a portion (i.e., approximately half) of the class sessions were conducted as blended classes, while the others were conducted as flipped classes. Four of the eight topics were delivered in the flipped mode, and the other four were taught in the blended fashion. The choice of the topics for each instructional mode was based on students' final exam performance over several previous semesters. Also during this semester, eight of the 14 multiple-choice questions on the final exam were based on material taught in the flipped mode, and the other six were based on material taught in a blended manner.

The video lectures used for all three instructional methods were developed as part of previous NSF-funded work. This open courseware, known as Holistic Numerical Methods (HNM), includes resources for introductory computing, differentiation, nonlinear equations, simultaneous linear equations, interpolation, regression, integration, ordinary differential equations, partial differential equations, optimization, and Fast Fourier transforms (Kaw et al., 2012). Between 2009 and 2012, 250 videos were developed and recorded for this open courseware initiative, with an average length of about nine minutes. The videos can be accessed using the following link: http://mathforcollege.com/nm/videos/index.html.

Study Participants

The following numbers of students were enrolled in the blended, semi-flipped, and flipped courses: 95, 27, and 58 respectively, totaling 180 students across three semesters from the spring 2014 to the fall 2014. The numbers of participants who provided data for this study were as follows: 73 (77%), 18 (67%), and 41 (71%), respectively, totaling 132 students. Of the 132 students, 18 (14%) were female. Additional demographic characteristics of the participants can be determined based on the sample sizes shown in Table 3 in the results section.

Assessment of Learning

Direct assessment of student learning based upon the final exam was used to investigate our first research question comparing achievement with the three methods. The final exam contained 14 multiple-choice questions that were identical across the three semesters. The multiple-choice questions were designed to test the lower-level skills in Bloom's taxonomy (Wiggins & McTighe, 2005). In addition, there were four open-ended, free-response questions that remained the same from term to term. These were intended to measure the higher-order skills in Bloom's taxonomy, such as synthesis. Using the multiple-choice and free response data, we compared the three instructional methods using an analysis of covariance (ANCOVA), with the pre-requisite GPA as the covariate or control variable. Since the summer term sample size was less than 20, we also ran a non-parametric analysis of covariance, known as Quade's test (Quade, 1967; Lawson, 1983). The *p*-values based on the parametric and non-parametric analyses were generally in agreement, and examining both served to corroborate the results. Nonetheless, we defaulted to the non-parametric result given the small sample sizes. We used Tamhane's T2 post-hoc comparison, which is conservative, to test significance between the individual pairs (Field, 2005). These analyses were conducted using the software SPSS 21. The pre-requisite GPA was based on the grades received in Calculus 1-3, ordinary differential equations, introductory programming, and physics 1.

We conducted a series of ANCOVA's and Quade's tests to analyze the data in a stratified fashion, comparing the instructional methods for each demographic segment of interest to our research. For example, we were interested in questions of the type: "For females, which instructional method is associated with the highest achievement?" We also ran an analysis of variance (ANOVA), its non-parametric variant (i.e., the Kruskal-Wallis test), and Tamhane post-hoc tests to determine if the instructional method was a factor for students of different achievement levels, as determined by the pre-requisite GPA. We used three GPA groups - under 3.00, between 3.00 and 3.49, and 3.50 and above. Finally, we ran an ANCOVA for each of the seven numerical methods topic areas to determine if the class as a whole performed better with flipped versus blended instruction for particular numerical methods topic areas.

Given the large number of tests we ran for each analysis family, we applied the Bonferroni correction to the individual *p*-values (Perneger, 1998; Bland & Altman, 1995). When a large number of statistical tests are performed, some will unfortunately result in $p < 0.05$ just by chance; therefore, if one continues to test long enough, a significant result will eventually occur (McDonald, 2014). The Bonferroni correction addresses this by reducing the alpha level applied to each individual test so that the family-wide error rate remains at $\alpha=0.05$. With this correction, the alpha level for each of our individual tests was set at (0.05/*m*), where *m* is the number of tests. Unfortunately, this correction has the drawback that it becomes very conservative as the number of tests increases; also, the interpretation of a finding is dependent on the number of other tests conducted. In other words, the type II error rate increases such that true differences may be deemed non-significant (Perneger, 1998). These disadvantages as well as the lack of a well-formulated definition of an "analysis family" surround the use of the Bonferroni correction (Miller, 1981). We present this information so the reader will be fully informed when interpreting our results.

In addition to determining significance levels, we calculated effect sizes based on Cohen's *d* for all pairs of means (Sullivan & Feinn, 2012; Kotrlik et al., 2011). The effect size represents the magnitude of the difference between two groups and provides a measure of practical or substantive significance. As discussed in the above two articles, both the significance level and the effect size should be determined and reported in order to show the overall result or the "big picture." Further, the *Publication Manual of the American Psychological Association* advises authors to include both the *p* value and the size of the effect (American Psychological Association, 2010). For, in order to appreciate the importance of the findings and convey the most complete meaning of the results, it is necessary to provide a measure of effect size, such as Cohen's *d* (American Psychological Association, 2010). A reference for engineers also recommends interpretation of both the magnitude of the observed change for practical significance and the *p* value (Hogg & Ledolter, 1992). We used the following threshold values to determine small, medium, and large effects, as delineated by Cohen: d=0.20 (small), d=0.50 (medium), and d=0.80 (large) (Cohen, 1987; Salkind, 2010). For the ANCOVA results, we calculated *adjusted* effect sizes based on the adjusted means (Huck, 2012). SPSS adjusts the means using the mean value of the covariate (Norusis, 2005).

Collection of Demographic Data for Stratified Direct Assessment

To directly assess learning for various demographic segments in a stratified manner, we developed a demographics survey for this research, to be used in conjunction with the final exam. It consisted of questions regarding age, gender, race/ethnicity, Pell grant status, transfer status, work and credit hours, and pre-requisite course grades. The pre-requisite courses consisted of calculus 1-3, ordinary differential equations, introductory programming, and physics 1. We also accounted for the possible fulfillment of these requirements through Advanced Placement (AP) test credits. These grades were used to calculate a numerical methods pre-requisite GPA for each student to be used as a covariate or control variable in the analysis of covariance of the blended vs. flipped vs. semi-flipped approach. The students were asked to provide a personal code when completing this survey, which allowed us to match the student's exam performance with his/her demographic characteristics and thereby evaluate various demographic segments of our population. The demographic segments of interest within our research were the following:

1. Age Group: {22 or under, over 22}
2. Gender: {male, female}
3. Under-Represented Minority (URM): {yes, no}
4. Transfer Status: {admitted to engineering as a freshmen, transferred to engineering from a community college with an Associate's degree, other transfer students}
5. Pell Grant Recipient: {yes, no}
6. Combined Work and Credit Hours Effort: {under 40, 40–65, over 65}

The age categories reflect our interest in traditional vs. non-traditional engineering students, with the traditional student starting college at age 18. The under-represented minority students consisted of Hispanic, American Indian, Black/African American, or Hawaiian/Pacific Islander students. The "other" transfer students consisted of internal-to-USF transfers to the engineering school, community college transfers without Associates' degrees, and transfers from external four-year programs. The Pell Grant Program provides need-based grants to low-income undergraduates for postsecondary education, and the amount depends in part on the financial need and the costs to attend school (Federal Pell Grant Program, 2015). The work and credit hours were combined by multiplying the credit hours by three and adding the weekly work hours. For the summer term, we used a slightly different multiplier. Sixty-five combined hours (65) corresponded to a full-time student taking 15 credits and also handling a 20-hour-per-week work study or other job, which would not be unusual for a student. The boundaries associated with this field resulted in a reasonable number of students in each category.

Classroom Environment Survey

We employed the College and University Classroom Environment Inventory (CUCEI) to investigate our second research question concerning student perceptions of the classroom environment with the three instructional methods (Fraser & Treagust, 1986). This reliable inventory evaluates perceptions of seven psychosocial dimensions of the classroom and has been used previously in flipped classroom research (Strayer, 2012; Clark et al., 2014). Several of the dimensions are particularly relevant to the flipped classroom, including student cohesiveness, individualization, innovation, involvement, and personalization, as shown in Table 2. There are seven questions per dimension, and each question has a scale of 1 to 5, with 5 being most desirable. An average score for the dimension was calculated for each student. These scores were then used to test for differences in the instructional methods by dimension. Specifically, we ran an ANOVA, Tamhane post-hoc tests, and the Kruskal-Wallis test for each dimension to determine if the instructional method was a significant factor in students'

Dimension	Definition
Student Cohesiveness	Students know & help one another
Individualization	Students can make decisions; treated individually or differentially
Innovation	New or unusual class activities or techniques
Involvement	Students participate actively in class
Personalization	Student interaction w/ instructor
Satisfaction	Enjoyment of classes
Task Orientation	Organization of class activities

Table 2. CUCEI Dimensions.

perceptions of the classroom environment. We distributed the CUCEI during the last week of class and collected the data anonymously to enable the most comprehensive and honest viewpoints. The students were offered extra credit for completing the surveys.

Flipped Classroom Evaluation Survey and Student Focus Groups

A flipped classroom evaluation survey and student focus groups were used to investigate our third research question about the benefits and drawbacks of flipped instruction in numerical methods from the students' perspectives. Our evaluation survey was modeled upon a previously-developed survey and used for both formative and summative assessment purposes. We employed many of the questions used by Zappe, Leicht and colleagues at Penn State, who used perception instruments in a flipped architectural engineering course (Zappe et al., 2009; Leicht et al., 2012). We used questions pertaining to preferences for flipped instruction and in-class active learning as well as video usage behavior. In addition, we expanded upon their questions given our specific research questions and interests. We added questions about the value of online homework, peer interaction, and the online discussion board; applicability to one's future career; perceived learning gains and the development of computer programming skills; level of perceived responsibility on the student; and student motivation with the flipped classroom. A copy of our survey is shown in Appendix A. As with the CUCEI, we distributed the evaluation survey during the last week of class and collected the data anonymously.

We also asked two open-ended questions on benefits as well as drawbacks and suggestions regarding the flipped classroom. A content analysis of each question was performed by a single coder, who was an upper-level engineering student. A second coder, the assessment analyst for the project, coded 50% of the responses to the benefits question to provide a measure of inter-rater reliability. The inter-rater reliability based on Cohen's Kappa was $\kappa = 0.75$, which suggests good agreement beyond chance (Norusis, 2005). The coding framework was developed using a grounded, emergent qualitative analysis as part of prior flipped classroom research by the assessment analyst (Neuendorf, 2002; Clark et al., 2014; Clark et al., 2016). The drawbacks/suggestion question was analyzed in the same manner, with the assessment analyst coding 48% of the responses to provide a measure of inter-rater reliability. The inter-rater reliability achieved for this question was $\kappa = 0.76$, showing strong agreement beyond chance (Norusis, 2005).

We also sought student perceptions and feedback using focus groups in the fully-flipped course. Focus groups provide a means to obtain qualitative information from a group of people on their experiences and perceptions, which can be used alongside survey data for triangulation purposes (Fitzpatrick, Sanders, & Worthen, 2011). We conducted two focus groups at approximately the three-fourths point in the semester, each consisting of a different student demographic. One of the groups consisted of white males, and the other group consisted of students other than white males, including Hispanic and female students. This was consistent with our interest in investigating these instructional methods for underrepresented minorities and females in engineering. In the discussion of our results, we discuss our survey and focus group data together to triangulate our findings. In the focus groups, we asked questions about the perceived benefits and disadvantages of the flipped classroom, including learning or professional growth, challenges or negative outcomes, individualized support, and impact on programming skills.

Since our focus group questions aligned with the open-ended questions from our flipped classroom evaluation survey, we used the coding framework for the open-ended questions to analyze the focus group responses in a structured way. The same two coders (i.e., the upper-level engineering student and the assessment analyst) coded the focus group data using the framework. Both components of the overall framework were used – the benefits as well as the drawbacks/suggestions. Even though the responses were double-coded, we calculated a first time reliability based on Cohen's kappa. The first time inter-rater reliability for use of the benefits framework with the focus group data was $\kappa = 0.79$, showing strong initial agreement. For the drawbacks/suggestions framework, $\kappa = 0.69$, showing fair initial agreement.

RESULTS

In this section, we provide a comparison of the final exam results for the three methods of instruction for various demographic segments to address our first research question. These final exam results are based on both multiple-choice and free response questions. Additionally, flipped versus blended results are provided for specific topic areas within numerical methods, such as integration and differentiation. We also provide results from the various student perception surveys (i.e., classroom environment and flipped-classroom evaluation) as well as the student focus groups to address our second and third research questions.

Direct Assessment of Learning

Comparison of Methods: Multiple-Choice Questions

We compared the multiple-choice results for the three instructional methods for all students as well as for various demographic segments of interest, as shown in Table 3. The *p*-values based upon the parametric and non-parametric analyses of covariance were generally in agreement. Given this and our tendency to default to the non-parametric analyses in the presence of the small sample sizes, only the non-parametric (i.e., Quade's Test) results are shown. Also shown are the adjusted mean scores (out of a possible 14 points), the *p*-values for the individual-level tests (i.e., prior to adjustment using Bonferroni's correction), Tamhane's post-hoc comparisons, and the sample sizes. Given the large number of possible effect sizes and limited table space, only effect sizes for those pairs with the smallest *p*-values are shown in Table 3. A list of all large effect sizes for the multiple-choice results can be found in Table 4.

As shown in Table 3, the flipped or semi-flipped method was always associated with a higher adjusted mean relative to the blended method. Given the 15 tests shown in Table 3, the α-level for each individual test was reset to 0.05/15 = 0.003. Although none of the individual tests would be considered significant upon applying this strict criterion, we did uncover several large effect sizes as shown in Tables 3 and 4, pointing to practical significance. For all students considered together, the effect size was medium (d=0.54) when comparing flipped versus blended instruction. For males, the semi-flipped adjusted mean was higher than the blended mean, and the effect size was large (d=0.90). For community college transfers with an Associate's degree, there was some evidence that the semi-flipped was better than the blended approach, in particular given the large effect size (d=1.09). For medium effort students (40–65 hours/week), both the flipped and semi-flipped methods had higher means than the blended approach, and the effect sizes were large. Non-minority students scored higher with semi-flipped versus blended instruction, and the effect size was medium (d=0.76). The small sample sizes associated with semi-flipped approach potentially influenced the levels of significance.

Additional large effect sizes pointing to practical significance were found for several pairs of methods. These additional pairs are provided in Table 4, along with those from Table 3. The reader will want to keep in mind that some demographic segments had small sample sizes in the semi-flipped classroom. However, notable are the results for "other transfer" students and medium-effort students, in which the effect sizes were large when comparing the flipped to the blended classrooms (d=1.37 and d=0.85, respectively). Recall that "other transfers" consisted of internal-to-USF transfers

Multiple-Choice (14 points)	Flip F	Semi-F SF	Blended B	Quade's Test			Cohen Effect Size d	F	SF	B
	Adjusted Mean			Overall p	Sig Pair	Post Hoc p		Sample Size		
All	9.57	9.86	8.37	0.016	F&B	0.053	0.54	41	18	73
Gender										
Male	9.57	10.32	8.34	0.008	SF&B	0.005	0.90	34	15	64
Female	9.60	6.99	8.65	0.417				7	2	9
Age										
<= 22	9.95	10.20	8.85	0.075				25	12	41
>22	8.95	8.53	7.74	0.402				16	4	32
Transfer										
Fresh Adm.	9.83	10.37	9.26	0.551				15	7	34
CC Assoc.	9.00	9.88	7.49	0.015	SF&B	0.074	1.09	18	9	33
Other	10.32	7.96	8.25	0.048				8	1	6
Effort										
<40	9.54	10.02	8.91	0.839				12	5	17
40-65	9.59	9.76	7.87	0.003	F&B SF&B	0.013 0.023	0.85 0.93	21	10	44
>65	9.35	11.06	9.37	0.459				7	2	12
URM										
Yes	9.32	8.66	7.87	0.232				19	4	13
No	9.82	10.18	8.47	0.027	SF&B	0.041	0.76	22	14	60
Pell Grant										
Yes	9.69	9.87	8.40	0.152				12	7	29
No	9.54	9.95	8.36	0.108				29	10	44

Note: The p-values shown are those *prior to* application of Bonferroni's correction.

Table 3. Multiple-Choice Questions – Comparison of Methods.

to the engineering school, community college transfers without Associates degrees, and transfers from external four-year programs. Another type of transfer student, community college transfers *with* Associates degrees, demonstrated greater achievement with the semi-flipped versus blended classroom (d=1.09), as did medium-effort students and males. These results, along with the adjusted means shown in Table 3, lead us to preliminarily conclude that some degree of flipped instruction may have been more beneficial than blended instruction for lower-order skills development in our numerical methods course.

Demographic	Mean 1	Mean 2	Cohen's *d*
Other Transfer	F	SF	1.56
Other Transfer	F	B	1.37
Female	F	SF	1.18
CC Transfer w/ Assoc.	SF	B	1.09
Effort 40-65	SF	B	0.93
Male	SF	B	0.90
Effort 40-65	F	B	0.85
Effort > 65	SF	F	0.84
Effort > 65	SF	B	0.83

Note: Mean 1 > Mean 2

Table 4. Large Effect Sizes (Multiple-Choice Questions).

Comparison of Methods: Free Response Questions

Although we anticipated that flipped instruction would emerge as the best method for the free response questions, as the students had to "dig deeper" on their own, we did not find statistically significant differences in the three methods for any demographic group. The results are provided in Table 5, in which the majority of the demographic segments scored highest with the semi-flipped approach (although not significantly so). For all students considered together, the semi-flipped approach was associated with the highest adjusted mean for the free response results; however, the associated effect sizes for the semi-flipped method compared to the other methods were small (d~0.30).

However, we did find several large effect sizes related to higher-order skills development in numerical methods, as shown in Table 6. Notable are the results for "other transfer" students, in which the effect size was large for flipped versus blended instruction (d=1.11). The under-represented minority (URM) students performed best with semi-flipped instruction, in which the effect sizes in comparison to flipped and blended instruction were large. Thus, based on Table 6, we have some initial data to suggest that flipped instruction (of some amount) may have been associated with enhanced higher-order skills attainment in our numerical methods course.

Comparison of Methods by GPA Groups

We also compared the instructional methods for students of different pre-course achievement backgrounds, as determined by the pre-requisite GPA. Students in the highest GPA group (i.e., 3.50 and above) scored higher with semi-flipped vs. blended instruction on the multiple choice questions, as shown in Table 7. The effect size was large (d=1.27), although the result was not significant after

Free Response (16 points)	Flip F	Semi-F SF	Blended B	Quade's Test			F	SF	B
	Adjusted Mean			Overall p	Sig Pair	Post Hoc p	Sample Size		
All	5.92	6.85	5.98	0.693			41	18	73
Gender									
Male	5.99	7.14	5.89	0.458			34	15	64
Female	5.57	5.00	6.78	0.342			7	2	9
Age									
<= 22	6.48	6.95	6.62	0.966			25	12	41
>22	5.11	5.56	5.12	0.871			16	4	32
Transfer									
Fresh Adm.	7.13	7.01	7.03	0.898			15	7	34
CC Assoc.	4.21	6.82	5.09	0.142			18	9	33
Other	7.63	4.91	5.34	0.099			8	1	6
Effort									
<40	4.63	8.22	6.26	0.197			12	5	17
40-65	6.45	6.64	5.78	0.624			21	10	44
>65	6.61	6.17	6.20	0.887			7	2	12
URM									
Yes	5.64	8.54	5.83	0.391			19	4	13
No	6.22	6.38	6.00	0.897			22	14	60
Pell Grant									
Yes	4.94	5.72	5.95	0.627			12	7	29
No	6.34	7.64	6.04	0.592			29	10	44

Note: The p-values shown are those *prior to* application of Bonferroni's correction.

Table 5. Free Response Questions – Comparison of Methods.

Demographic	Mean 1	Mean 2	Cohen's d
Other Transfer	F	SF	1.31
Other Transfer	F	B	1.11
URM – Yes	SF	F	1.04
Effort < 40	SF	F	1.00
URM - Yes	SF	B	0.97
Female	B	SF	0.97
CC Transfer w/ Assoc.	SF	F	0.95

Note: Mean 1 > Mean 2

Table 6. Large Effect Sizes (Free Response Questions).

	Flip F	Semi-F SF	Blended B	ANOVA p	K-W p	Sig Pair	Post Hoc p	Cohen Effect Size d	F	SF	B
	Mean								Sample Size		
Multiple-Choice											
Prerequisite GPA											
Under 3.00	9.18	8.71	7.61	0.111	0.134				11	7	28
3.00 to 3.49	9.30	9.00	8.27	0.368	0.630				20	4	26
3.50 +	10.70	11.86	9.42	0.019	0.033	SF&B	0.041	1.27	10	7	19
Free Response											
Prerequisite GPA											
Under 3.00	5.09	4.71	5.11	0.939	0.922				11	7	28
3.00 to 3.49	6.05	5.50	5.39	0.757	0.664				20	4	26
3.50 +	6.80	10.29	7.79	0.069	0.091				10	7	19

Note: The *p*-values shown are those *prior to* application of Bonferroni's correction.

Table 7. GPA Groups – Comparison of Methods.

applying the Bonferroni correction. The free response score for this top GPA group was also highest with the semi-flipped approach, and the associated effect sizes were large, with d=1.17 and d=0.84 when comparing to the flipped and blended methods, respectively. For the other GPA groups, the effect sizes were medium or small, with a maximum absolute value of d=0.72.

Comparison of Methods by Topic Area

To investigate whether certain instructional methods might be better for certain numerical methods topic areas, we compared the results of the multiple-choice questions associated with each of the seven topic areas in the course, using the prerequisite GPA as the control variable. We used data from the two semesters in which fully-flipped and blended instruction were used, as shown in Table 8. Based on an ANCOVA, there were four topic areas for which the flipped method resulted in higher scores. The most notable difference was for the introductory scientific computing area, which had a medium effect size of d=0.73. Given the highly significant result associated with scientific computing (p<0.0005), the difference is significant even after applying Bonferroni's correction (0.05/7=0.007). This topic area covers motivations for using numerical methods, their applications, and identification and handling of error. A substantial difference occurred for nonlinear equations, which had higher scores with flipped instruction and a medium effect size. Differences for differentiation and simultaneous linear equations are also notable. The other topic areas had small effect sizes. Each topic area was associated with two questions worth one point each. Based

Topic Area (2 points each)	Flip F	Blended B	ANCOVA p	Cohen Effect Size d	F	B
	Adjusted Mean				Sample Size	
Differentiation	1.55	1.27	0.026	0.44	41	73
Integration	1.41	1.50	0.427	0.15	41	73
Interpolation	1.31	1.41	0.425	0.16	41	73
Scientific Computing	1.43	0.93	<0.0005	0.73	41	73
Nonlinear Eq.	1.16	0.81	0.009	0.51	41	73
Ordinary Differential Eq.	1.51	1.46	0.722	–0.07	41	73
Simultaneous Linear Eq.	1.19	0.96	0.059	0.37	41	73

Note: The p-values shown are those *prior to* application of Bonferroni's correction.

Table 8. Topics Areas – Comparison of Flipped vs. Blended.

on these results, flipped instruction may have been the better approach for several topic areas when considering the students as a whole.

Student Perceptions and Preferences

Classroom Environment Inventory

To assess the psychosocial dimensions of our three classroom environments and investigate our second research question about perceptions of the learning environments, we used Fraser's College and University Classroom Environment Inventory (CUCEI) as shown in Table 9. We obtained response rates in the range of 67% to 78% of the class enrollments across the three classrooms. Upon applying Bonferroni's correction, there were no significant differences with the classroom environment dimensions. Task orientation, which was associated with the smallest p-value, was rated higher in the blended and semi-flipped classrooms versus the flipped classroom. This perception of less organization in the flipped classroom makes sense, as students were expected to conduct their own problem solving efforts with the instructor present to guide. Thus, in general, the classroom environments were statistically equivalent across the three methods of instruction. All Cohen's d effect sizes were less than 0.50 in absolute value, indicating small effects.

Although not statistically significant, the following trends were noticed. The flipped mode was rated lower than the blended mode on six of the seven dimensions. The semi-flipped mode was rated lower than the blended mode on four of the seven dimensions. This leads to the following question: Do students prefer the environment of the blended classroom to the flipped (or semi-flipped)

Dimension		Flip F (n=43)	Semi-F SF (n=18)	Blended B (n=74)	ANOVA *p*	K-W *p*	Sig Pair	Post Hoc *p*	Cohen Effect Size *d*
		Mean							
Cohesiveness	Students know & help one another	2.80	2.93	3.07	0.19	0.18			
Individualization	Treated individually or differentially	2.61	2.51	2.45	0.22	0.39			
Innovation	Novel class activities or techniques	2.92	2.99	3.09	0.23	0.19			
Involvement	Active participation in class	3.29	3.22	3.31	0.87	0.66			
Personalization	Interaction w/ instructor	4.06	3.90	4.13	0.41	0.21			
Satisfaction	Enjoyment of classes	3.51	3.73	3.61	0.65	0.69			
Task Orientation	Organization of class activities	4.08	4.32	4.31	0.045	0.055	B&F	0.068	0.47

Note: The *p*-values shown are those *prior to* application of Bonferroni's correction.

Table 9. Classroom Environment – Comparison of Methods.

classroom for numerical methods? The further collection of data will enable us to answer this question with more certainty. The small sample size in the semi-flipped section likely influenced the significance levels and contributes to the preliminary nature of these results. As might be expected, individualization was rated higher in the flipped classroom versus in the other classrooms, although not significantly so. This dimension measures individual or differential treatment, which is possible with in-class problem solving efforts.

Flipped Classroom Evaluation Survey

The students evaluated the flipped portion of the summer course as well as the fully-flipped course in the fall via a flipped classroom evaluation survey, with approximately 68% of enrolled students responding. This, in conjunction with the student focus groups, enabled the investigation of our third research question about the perceived benefits and drawbacks of flipped instruction. Thirty-eight percent (38%) of the respondents preferred the flipped classroom to usual methods of instruction. Another 38% were unsure of their preferences, and 24% did not prefer flipped instruction. In a recent school-wide initiative, a similar pattern involving an approximate three-way split in student preference for the flipped classroom was found, with 27% indicating a preference, 36% indicating a non-preference, and 36% being unsure (Clark et. al., 2016).

However, when asked to compare the use of class time for problem solving with the instructor present versus listening to a lecture, 54% of the numerical methods respondents preferred the former. In comparison, Zappe et al. found slightly lower student preference for active learning in the classroom, with 48% agreeing or strongly agreeing that they preferred problem solving versus lecture during class time (Zappe et al., 2009). This pattern of a lower preference for the flipped classroom overall compared to a higher preference for active learning during class has been noted previously (Bishop & Verleger, 2013). These researchers offered the explanation that students tend to prefer in-person lectures to video lectures but ultimately prefer classroom activities to lecture.

In terms of required effort, over 77% of respondents reported that this flipped classroom required more or much more effort compared to usual methods of instruction, and 84% felt it placed more or much more responsibility on them. In his post-course interview, the instructor also noted that students were given (and assumed) more responsibility for their own learning with the flipped format; as discussed in the introduction, this was one of his goals with flipping the course.

The respondents felt the online, auto-graded, multiple-attempt homework problems were valuable (79% agreement or strong agreement), as was the discussion board (74% agreement or strong agreement). In terms of other aspects of the flipped classroom, 36% agreed or strongly agreed that the learning gains were better in the flipped classroom. Forty-four percent (44%) agreed or strongly agreed that interaction with their peers in the flipped classroom was valuable. Thirty-four percent (34%) thought the flipped classroom led to valuable experiences for their future careers. Finally, only 25% felt the flipped classroom enabled them to develop better computer programs for numerical methods solutions.

We asked the students who received some degree of flipped instruction to report the percentage of videos on the assigned topics they watched. The average percentage reported was 62%. However, the videos were not the only available resource for learning the material; students were also directed to the book chapters, which were online as well as in hardcopy format. In fact, 79% of survey respondents reported using a combination of the videos and the book chapters. Only one student reported using just the videos. In a post-course interview, the instructor felt that students took responsibility for the self-learning aspect of the flipped classroom during both the summer and fall terms. In a first-year engineering course that used pre-class videos, the students who reported having prepared for class also used a combination of readings and videos. The authors concluded that providing students with a variety of options for their preparation was desirable (Hamlin et al., 2014).

Content Analysis of Benefits

In an open-ended question on the flipped classroom evaluation survey, we asked the students what they liked about the flipped classroom and the benefits they perceived. The frequencies associated

Frequency	% of Respondents	Category	Description
25	43%	Enhanced Learning or Learning Process	Better understanding; less confusion Enhanced learning/effectiveness/depth/ability Subject matter retention Multiple sources/resources for understanding Reinforcement and review Multiple attempts
20	34%	Preparation, Engagement & Professional Behaviors	Engaged during class; paid attention; not bored Enjoyed class Arrived to class prepared Ability to learn on one's own Drove motivation and accountability
13	22%	Video/Online Learning	Re-watch videos Work at one's own pace; pause video Flexibility, convenience, own preferences Modularization of topics
10	17%	No Benefit or Neutral Result	No benefits perceived Did not like flipped instruction Videos not used Instructional differences not noticed
8	14%	Alternative Use of Class Time	In-class active learning, problem solving, clickers In-class support and questions In-class group time for projects Student interactivity and peer support
4	7%	Specific to Course or Course's Videos	Videos concise Videos had a good pace Overall work time less Videos had relevant content (e.g., demo or examples) or were of high quality

Table 10. Summary of Open Ended Responses to Benefits.

with the categories in our coding framework are shown in Table 10. To our satisfaction, the most frequently perceived benefit was enhanced learning or learning processes, as perceived by 43% of respondents. This was similar to the result from our closed-ended question about learning gains, in which 36% agreed or strongly agreed that the learning gains were better with the flipped classroom. In addition, thirty-four percent (34%) identified preparation, engagement, and professional behaviors as a benefit. In his post-course interview, the instructor identified life-long learning skills as a benefit to the students. His flipped classroom aimed to prepare students to be able to learn on their own for when they are working for a company someday. In addition, he wanted to prepare students to independently learn using multiple sources, such as books, videos, or other online content, as today's world is replete with a multitude of informational formats. In summary, one-third to almost one-half of the respondents perceived the top benefits that we were hoping to achieve with the flipped classroom. These results were based on a content analysis of 58 student responses.

Comparison with Focus Group Results

In our focus groups, enhanced learning and learning processes, the alternative use of class time, and engagement and professional behaviors were the three benefits identified most frequently by each of the demographic groups (i.e., white males as well as underrepresented minority and female students). This aligned fairly closely with the results of the open ended question about the benefits. The white males indicated that the flipped classroom led to deeper learning because of the need to explore material on their own. Also, one could spend as much time as needed to understand something. In the focus group with students other than white males, better understanding and a better idea of mechanical engineering, including everyday scenarios, were stated as benefits of the flipped classroom. For both demographics, reinforcement and review of lecture material and a variety of resources created enhanced learning processes. Both demographics also highlighted the alternative use of class time in the form of the ability to ask questions and receive support during class as benefits. For both demographics, the third most frequently identified benefit was the connection between the flipped classroom and their future professional careers as well as their engagement and preparation for class. The white males in particular stated that the flipped classroom was good professionally because it encouraged responsibility for one's own learning. The underrepresented minority and female students explained that the videos will be a valuable resource in the future, as it is difficult to keep in mind every possible numerical method that could be applied. Also, the flipped classroom promoted motivation, in-class engagement, and preparation with both demographics. When comparing the focus group results between the two demographic groups using the coding framework (i.e., Table 10), there was very little difference in the responses.

Content Analysis of Suggestions and Drawbacks

In a second open-ended question on the evaluation survey, we asked the students what drawbacks they perceived with the flipped classroom and suggestions for improvement. The frequencies associated with the categories in our coding framework are shown in Table 11. The most frequent suggestions or drawbacks pertained to the use of in-class time, as identified by 43% of respondents. This was followed by the perceived load, burden, or stressors on the students (34% of respondents), such as an increased time burden. Eleven percent (11%) of the respondents suggested better preparing and equipping students for flipped instruction. The results in Table 11 were based on a content analysis of 56 student responses.

Comparison with Focus Group Results

In our focus groups, the three drawbacks/suggestions identified most frequently were related to the use of class time, workload and stressors, and preparation for the flipped style of instruction.

Frequency	% of Respondents	Category	Description
24	43%	In-Class Time	Increase time for active learning or problem solving Increase effectiveness or relevancy of problems; grade them Provide appropriate amount of lecture or content review Have more instructor-types during class to assist Synchronize class activity and video content
19	34%	Load, Burden, Stressors	Insufficient time to complete out-of-class activities Increased work load Increased time burden Concerns over grades or impacts to the grade Accountability quizzes (including surprise)
10	18%	Specific to Course or Course's Videos	Include more examples or problems in the videos Videos needed editing or bug/technical fixes Videos were too long Videos were not sufficiently described Videos were dry or boring Videos did not have an appropriate pace Videos repeated information Video material was too complex
7	13%	No Drawbacks or Neutral Result	No drawbacks or suggestions
6	11%	Approach Differently	Do not flip courses in general; use traditional teaching Do not flip this course in particular Provide students with a choice on flipping Flip only a portion of the class periods
6	11%	Prepare, Equip & Incentive Students To Flip	Prepare students for the flipped learning style Incentivize students, including video quizzes Clarify/emphasize expectations, including video watching Provide video "lecture" notes Ensure videos available in advance for students
5	9%	Student Learning	Lesser understanding or learning Difficulty learning from a video
2	4%	Video/Online Learning	Students unable to ask questions during a video Instructor unable to sense student understanding in a video Distractors to viewing videos in a non-classroom setting Less motivation to attend class

Table 11. Summary of Open Ended Responses to Suggestions/Drawbacks.

This aligned closely with the results of the open-ended question, as shown in Table 11. The non-white males identified suggestions for the improved use of class time more frequently than the white males did, including more or alternative in-class activities and problems as well as additional in-class review of questions and concepts related to the clickers or MATLAB. Specifically, the non-white males suggested that more problems and examples be provided during class, including more difficult and in-depth problems. Another request or suggestion was to do more active learning during class in the form of MATLAB programming, using laptops if necessary. According to these students, this would drive confidence and lessen their difficulties with programming, because the instructor would be present to answer questions and assist. The white males noted to a larger extent the load or stressors they felt with the course, most notably increased work or time. Both demographics equally emphasized the need to prepare and equip students for the flipped classroom. This included suggestions that the instructor fully explain at the start of semester that the course is being flipped and that he/she clarify exam expectations in the new class format.

DISCUSSION OF RESULTS

Considering our first research question, the flipped or semi-flipped method was typically associated with a higher adjusted mean versus the blended method for either the multiple-choice or free-response exam questions. In addition, although none of the tests was significant upon applying Bonferroni's correction, we found several large effect sizes for flipped or semi-flipped versus blended instruction, leading us to preliminarily conclude that some degree of flipped instruction may have been better than blended learning for achievement in the course. Specifically, for all students considered together, the effect size was medium (d=0.54) for flipped versus blended instruction when examining lower-order skills attainment. There were some promising trends for transfer students to the college of engineering. For those students who transferred with a community college Associate's degree, we found some evidence that semi-flipped instruction may have been better than blended instruction, given the large effect size (d=1.09). For "other" transfer students, we found large effect sizes for flipped versus blended instruction for both lower-order and higher-order skills achievement (d=1.37 and d=1.11, respectively). Although our results do not point to significant differences at this point for URM students, the effect sizes were large for semi-flipped instruction versus the other two methods for the higher-order skills.

When comparing these methods for students of varying pre-course achievement backgrounds, we found a large effect size for the highest GPA group and the multiple-choice questions, in which semi-flipped exceeded blended performance. Finally, we found a significantly-higher score for flipped versus blended instruction for the scientific computing topic area (p<0.0005), with a medium effect size (d=0.73). We also found a substantial difference and a medium effect size for nonlinear equations, with flipped exceeding blended instruction. Based on these various analyses, we conclude in relation to our first research question that flipped instruction may have led to greater achievement for certain numerical methods topic areas versus a purely blended approach.

Although exam results seemed to favor some degree of flipped instruction, the classroom environment results may have favored the blended approach, coinciding with our second research question. Although the classroom environment was actually statistically equivalent across the three methods, with small effect sizes, the flipped classroom was rated lower than the blended classroom on six of the seven dimensions, and the semi-flipped was rated lower than the blended mode on four dimensions.

Regarding the third research question, our students tended to view the flipped classroom as demanding, with large percentages reporting increased effort and responsibility required on their part. One possible explanation for the perceived greater effort is the inability for students to be passive during class. Thus, although the flipped classroom may not require more time overall, it does require students to be active during class. Although just 38% preferred the flipped classroom, 54% stated a preference for solving problems in class versus listening to a lecture. The most frequently-stated benefits of flipped instruction, as determined through a content analysis of an open-ended question, were enhanced learning or learning processes (43% of respondents); preparedness, engagement, and professional behaviors (34%); and conveniences afforded by video learning (22%). This was corroborated by the focus group results, in which the three benefits identified most frequently were enhanced learning or learning processes, the alternative use of class time, and engagement and professional behaviors. When asked about the benefits of flipped instruction in a post-course interview, the instructor also corroborated these findings, identifying life-long learning, career preparation, and enhanced responsibility for learning.

Study Limitations

Our study is a quasi-experimental design, as are many educational intervention studies, given the non-random assignment of students to the three classrooms that were compared. However, to control for a student's previous academic performance, a likely confounding factor, we used the pre-requisite GPA as a control variable in our analysis of their exam scores. Furthermore, we believe that more data is needed to fully investigate the research questions, especially given the large number of demographic tests and Bonferroni's correction. The sample sizes associated with some of the demographics segments are small, impacting significance levels and the ability to draw conclusions. This additional data will be collected over the remainder of our research grant. We did, however, use conservative statistical procedures (i.e., non-parametric tests and effect sizes) in the presence of these small samples.

Related to this, we acknowledge that our study was done with engineering students from one university. Therefore, these students may not be a representative sample of all engineering students who take numerical methods, thereby limiting the generalizability and applicability of the results to other students at other schools. In addition, this study involved just one instructor, albeit a seasoned numerical methods instructor. Although a single instructor allowed for more controlled comparisons among the methods, it is possible that our results would be different if another instructor had developed and taught the course. To this end, our grant involves two additional universities. Once these two additional instructors complete their flipped implementations using the same methods as described here, we will be able to add to our findings and report results of students from three schools and three engineering disciplines. Thus, instructors will want to keep in mind that we consider our results preliminary at this point; however, the trends we have demonstrated will contribute to our overall findings at the completion of the grant study.

Future Research

As discussed in the introduction, enhancement of metacognitive skills was one of the instructor's main goals in flipping the course, along with enhanced responsibility and higher-order skills development. Although we did not directly assess students' metacognitive skills, this may be a desirable future research line. In his post-course interview, the instructor discussed that the open-ended responses submitted by the students before class, which contained points of difficulty or interest, were of much higher quality and complexity in the flipped versus blended classrooms. He also explained that students were required to re-do and reflect on exam questions they did not get correct during each of the three semesters. Each student had to provide a small essay explaining why he/she got the problem wrong and why his/her re-submission was correct. The instructor was very pleased with the students' reflections, stating that the submissions were of extremely good and similar quality across the three semesters. Some students even pointed out they were not prepared in some cases for the exam questions. Since reflection is a valuable component of engineering practice, we suggest future research to determine whether there are measurable differences among these instructional methods in regards to student metacognition.

In addition, despite greater effort and responsibility perceived during the course by students, they still saw longer-term benefits with flipped instruction, including enhanced learning processes and career preparation. Therefore, should we be assessing the impacts of flipped instruction further into the future with our students? This is a great research opportunity, and we may be pleased to learn the outcomes. Related to this, instructors and researchers may wish to identify and consider additional direct assessment outcome variables (besides exam scores) to better demonstrate significant differences or improvements with the flipped classroom.

CONCLUSIONS

Blended, flipped, and semi-flipped approaches to teaching a mechanical engineering course in numerical methods were taken at the University of South Florida beginning in the spring of 2014. This enabled a comparison of these modalities in terms of student performance on both multiple-choice and free response exam questions and classroom environment perceptions. This paper is believed to be one of the first such comparisons within engineering education. The instructor has been teaching this course in a fully-guided, blended fashion for approximately 20 semesters and transitioned to a fully-flipped format in the fall 2014. With the flipped instruction, students applied and practiced concepts and skills initially obtained outside the classroom. Blended instruction involved maintaining the traditional in-class lecture enhanced by online and technology-based resources, including clickers, online quizzes, a discussion board, and a library of videos. The semi-flipped approach incorporated both of these instructional methods during the semester in an approximately-equal split of the time.

Based on our exam results, we believe that flipped instruction (or some degree of it) may have been the preferred method for achievement in our numerical methods course, relative to blended instruction. The instructor's preferred format for teaching this course is the semi-flipped approach, which he believes allows more time to guide students through difficult problems and is less impacted by larger class sizes. The classroom environment, however, was rated highest in the blended classroom, although not significantly so. Students perceived both benefits and drawbacks with flipped instruction. Although the needed effort and responsibility levels were perceived as higher in the flipped classroom, longer-term benefits were realized as well, including career preparation, professional behaviors, and enhanced learning or learning processes. The students tended to have suggestions for the use of class time in the flipped environment, including more hands-on practice with MATLAB programming or exposure to more challenging problems. As we continue to study these important research questions, we anticipate adding to our understanding of blended versus flipped instruction as regards achievement and preferences in numerical methods, in particular for non-traditional and under-represented students.

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APPENDIX A

Flipped Classroom Evaluation Survey (modeled upon Zappe et al., 2009)

	Question	Response Options or Type
1	Do you prefer a flipped classroom over the usual method of instruction in this class?	❍ Yes ❍ No ❍ Not sure yet
2	Please indicate the method that best describes how you completed your out-of-class learning.	❍ I only viewed the videos. ❍ I only read the book chapters. ❍ I used a combination of the videos and the book chapters. ❍ I used other resources. ____________________ ❍ I did NOT use the videos, book chapters, or any other resources for out-of-class learning.
3	What percentage of the videos on the assigned topics did you watch? (Approximate as needed, and use 0 or 100 as appropriate.)	0–100%
4	When did you primarily view the videos?	❍ Before the class period for which they were assigned ❍ After the class period for which they were assigned
5	How often did you re-watch the videos or any portions of them?	❍ Never ❍ Rarely ❍ Sometimes ❍ Often ❍ Almost always or always
6	Why did you re-watch videos or portions of them? (Select all that apply)	❍ The topic was difficult or challenging to grasp. ❍ The instructor's explanation in the video was not clear. (Please provide specifics)______ ❍ To reinforce my understanding as I was learning new material. ❍ To review or study course material prior to an exam or homework problem. ❍ Poor audio or visual quality of the video or other technical difficulty. (Please provide specifics) ________ ❍ Other (Please provide specifics) ________
7	With the flipped classroom, how would you rate the overall effort required of you, compared to the usual method of instruction in this class?	❍ Much less ❍ Less ❍ About the same ❍ More ❍ Much more
8	How would you rate the overall effort required of you in this class compared to other college/university engineering classes (either flipped or non-flipped) that you've taken or are currently taking?	❍ Much less ❍ Less ❍ About the same ❍ More ❍ Much more
9	I prefer using class time for hands-on activities or problem solving exercises (with the instructor or TAs present for assistance) rather than listening to a lecture.	❍ Strongly disagree ❍ Disagree ❍ Neutral ❍ Agree ❍ Strongly agree
10	The online, automatically-graded, multiple-attempt homework problems were valuable to my learning in this course.	❍ Strongly disagree ❍ Disagree ❍ Neutral ❍ Agree ❍ Strongly agree

	Question	Response Options or Type
11	I often did NOT know how to begin solving the in-class problems assigned in the flipped classroom.	❍ Strongly disagree ❍ Disagree ❍ Neutral ❍ Agree ❍ Strongly agree
12	With the flipped classroom, how would you rate the responsibility placed on you, compared to the usual method of instruction in this class?	❍ Much less ❍ Less ❍ About the same ❍ More ❍ Much more
13	I am NOT able to learn from a video.	❍ Strongly disagree ❍ Disagree ❍ Neutral ❍ Agree ❍ Strongly agree
14	The flipped classroom enabled me to gain valuable experience for my future career.	❍ Strongly disagree ❍ Disagree ❍ Neutral ❍ Agree ❍ Strongly agree
15	I had greater learning gains with the flipped classroom versus the usual method of instruction in this class.	❍ Strongly disagree ❍ Disagree ❍ Neutral ❍ Agree ❍ Strongly agree
16	More time needed to be spent during class reviewing the video or course content.	❍ Strongly disagree ❍ Disagree ❍ Neutral ❍ Agree ❍ Strongly agree
17	The ability to learn from and assist my fellow students in the flipped classroom was a valuable learning outcome for me.	❍ Strongly disagree ❍ Disagree ❍ Neutral ❍ Agree ❍ Strongly agree
18	With the flipped classroom, I had the motivation to engage in the necessary learning outside of the classroom.	❍ Strongly disagree ❍ Disagree ❍ Neutral ❍ Agree ❍ Strongly agree
19	I understand the reasons or rationale for the flipped classroom style in this course.	❍ Strongly disagree ❍ Disagree ❍ Neutral ❍ Agree ❍ Strongly agree
20	The flipped classroom enabled me to develop better computer programs for numerical methods problems.	❍ Strongly disagree ❍ Disagree ❍ Neutral ❍ Agree ❍ Strongly agree

	Question	Response Options or Type
21	The course discussion board was a valuable component of my learning.	❍ Strongly disagree ❍ Disagree ❍ Neutral ❍ Agree ❍ Strongly agree
22	What did you like most about the flipped classes and what benefits did you perceive?	Open ended
23	What suggestions do you have for improving the flipped classes and what drawbacks did you perceive?	Open ended