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Evaluating Blended and Flipped Instruction in Numerical Methods at Multiple Engineering Schools

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Abstract

With the literature calling for comparisons among technology-enhanced or active-learning pedagogies, a blended versus flipped instructional comparison was made for numerical methods coursework using three engineering schools with diverse student demographics. This study contributes to needed comparisons of enhanced instructional approaches in STEM and presents a rigorous and adaptable methodology for doing so. Our flipped classroom consisted mostly of in-class active learning, with micro-lectures as needed, and technology used both in and out of class, including for expected pre-class review of new content. Our blended classroom consisted mostly of lecture with some in-class active learning, and technology utilized both in and out of class. However, students were not expected to review new content before class. We compared blended vs. flipped instruction based upon multiple-choice and free-response questions on the final exam as well as the perceived classroom environment. This was done for students as a whole as well as for under-represented minorities (URMs), females, community college transfers, and Pell Grant recipients. Students provided feedback via focus groups and surveys. Upon combining data from the schools, the *blended* instruction was associated with slightly greater achievement on the multiple-choice questions across various demographics, but the differences were not statistically significant, and the effects were small. Our free-response final exam and classroom environment data aligned, with blended instruction showing more promise at two schools. The students identified demanding expectations with flipped instruction but pointed to benefits, such as enhanced learning or learning processes, preparation, and engagement. These results aligned with our focus group and instructor interview data. Thus, in general, it may be possible to use either instructional approach with the expectation of similar outcomes in final exam scores or the perceived classroom environment, keeping in mind the students qualitatively identified benefits with flipped instruction. Nonetheless, there were some large differences for the schools individually, suggesting further research with different demographics.

Keywords

Flipped class, Blended instruction, Numerical Methods

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Evaluating Blended and Flipped Instruction in Numerical Methods at Multiple Engineering Schools

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With the literature calling for comparisons among technology-enhanced or active-learning pedagogies, a blended versus flipped instructional comparison was made for numerical methods coursework using three engineering schools with diverse student demographics. This study contributes to needed comparisons of enhanced instructional approaches in STEM and presents a rigorous and adaptable methodology for doing so. Our flipped classroom consisted mostly of in-class active learning, with micro-lectures as needed, and technology used both in and out of class, including for expected pre-class review of new content. Our blended classroom consisted mostly of lecture with some in-class active learning, and technology utilized both in and out of class. However, students were not expected to review new content before class. We compared blended vs. flipped instruction based upon multiple-choice and free-response questions on the final exam as well as the perceived classroom environment. This was done for students as a whole as well as for under-represented minorities (URMs), females, community college transfers, and Pell Grant recipients. Students provided feedback via focus groups and surveys. Upon combining data from the schools, the blended instruction was associated with slightly greater achievement on the multiple-choice questions across various demographics, but the differences were not statistically significant, and the effects were small. Our free-response final exam and classroom environment data aligned, with blended instruction showing more promise at two schools. The students identified demanding expectations with flipped instruction but pointed to benefits, such as enhanced learning or learning processes, preparation, and engagement. These results aligned with our focus group and instructor interview data. Thus, in general, it may be possible to use either instructional approach with the expectation of similar outcomes in final exam scores or the perceived classroom environment, keeping in mind the students qualitatively identified benefits with flipped instruction. Nonetheless, there were some large differences for the schools individually, suggesting further research with different demographics.

INTRODUCTION

It can be difficult to engage students using traditional lecture; however, many educators have proposed (and research has shown) that engaged and involved students learn more and are better prepared (Novak et al., 1999; Astin, 1985; Pascarella & Terenzini, 2005; Kuh et al., 2005). Recently, educators have characterized the teaching of STEM courses using only traditional lecture as an ineffective and inferior approach (Mazur, 2009; Freeman et al., 2014; Wieman, 2014). In addition, educators have begun calling for comparisons of active or enhanced learning methods, as opposed to using traditional lecture as the control or comparison group, given the advantages of active learning (Freeman et al., 2014; Wieman, 2014; Weimer, 2016 March 9).

When students are passive during lecture, they retain less (Novak et al., 1999). A review of research in the 1990s showed the most effective practices require student involvement and participation, although the authors cautioned against dismissing lecture completely (Pascarella & Terenzini, 2005). Other recent studies have shown that active or interactive learners achieve significantly better (compared to passive learners) in problem-solving, time to mastery, conceptual understanding, and exam performance (Chi, 2009; Hake, 1998; Freeman et al., 2014). Other educators have stressed that true learning occurs with "doing" and that classroom discussion leads to greater learning gains and engagement (Prince, 2004; Bonwell & Eison, 1991; Howard, 2015).

Blended learning can provide more engaging experiences by integrating technology and/or replacing some aspects of face-to-face teaching with online learning, often maintaining a traditional class format (i.e., mostly lecture) nonetheless (Garrison & Vaughan, 2008; Bourne et. al, 2005; Dziuban et al., 2006). These online experiences may include simulations, labs, tutorials, and assessments (Garrison & Vaughan, 2008). Technology use often creates an active environment (Carr et al., 2015). Blended learning has the objective of "using the web for what it does best, and using class time for what it does best" (Osguthorpe & Graham, 2003, 227). It represents the convergence of historically separate models – face-to-face and computer-supported models that accommodate interaction (Graham, 2006). The flipped classroom, however, uses class for active learning and interactions, with students watching lecture videos beforehand (Bergmann & Sams, 2012). Students apply concepts during class, and instructors serve as consultants (Velegol et al., 2015). Blended learning and the flipped classroom are closely related to Just-in-Time-Teaching, which uses web resources for preparation and adjusts lectures to outcomes on pre-class assignments (Novak et al., 1999).

Our blended classroom consisted mostly of lecture with some group-based, in-class active learning, and technology utilized both in and out of class. This technology consisted of clickers, a continuously-available discussion board, and online quizzes, videos, and textbook content. Students were not expected to review new content prior to class. Our flipped classroom con-

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sisted mostly of in-class active learning with peer and instructor interaction and micro-lectures as needed, with the same technology (as mentioned previously) used in and out of class. However, students in the flipped classroom were expected to review new content before class via the videos or online readings. Our flipped and blended classrooms therefore combined elements of the Connectivism, Cognitive Apprenticeship, and Social Development learning theories (Siemens, 2005; Collins et al., 1989; Vygotsky, 1978). Connectivism takes into account technology and networks and the connections they enable. In our classrooms, students had digital resources and the Piazza discussion board through which they connected (Piazza, 2015). In a Cognitive Apprenticeship, students learn skills through expert guidance, as in a skilled-trades apprenticeship (Collins et al., 1989). This scaffolding is possible in the flipped classroom as the instructor circulates to assist with problem-solving. Vygotsky's Social Development Theory highlights the social, interactive, and cooperative nature of learning, another feature of our active-learning classrooms (Vygotsky, 1978).

In a preliminary study with one university, our research showed that the final exam results favored some degree of flipped instruction (either fully or semi-flipped), relative to blended instruction for numerical methods; however, trends in the classroom environment favored the blended approach (Clark et al., 2016a). The classroom environment measurement included dimensions such as student cohesiveness, student participation in class, and student interaction with the instructor, among others. Further, the second author previously compared four teaching methods, including blended and flipped, for one numerical methods topic (Kaw & Hess, 2007). Here, the flipped and blended methods had the highest final exam scores, respectively, although instructional value was rated highest by students for the blended method. Our present research aims to add to these findings and increase generalizability using two additional diverse schools. Our research is one of the few such STEM studies we are aware of.

An NSF grant enabled this research at three U.S. universities between 2014 and 2016 (Kaw et al., 2013). These universities differ, thereby adding to the generalizability. Based on the Carnegie Classification, all three are public. The University of South Florida (USF) and Arizona State University (ASU) are classified as "highest research activity" doctoral universities, with about 42,000 students at USF and 80,000 at ASU. Alabama A&M University (AAMU) is classified as a Master's college/university and an HBCU (Historically Black College/University) with about 5,000 students (Carnegie Classification, 2016). In investigating blended versus flipped instruction, our research questions were as follows:

1. Are there achievement differences when using blended versus flipped instruction for numerical methods coursework at various undergraduate institutions, and are differences evident for underrepresented minorities, females, community college transfers, and Pell Grant recipients?
2. Do students' perceptions of the classroom environment differ when using blended versus flipped instruction for numerical methods coursework at various undergraduate institutions?
3. What do students perceive as benefits and drawbacks of a numerical methods flipped classroom?

Our goal was to develop recommended practices for teaching numerical methods and other STEM courses using active, technology-enhanced approaches to potentially optimize how STEM is taught. In the following sections, we review the literature on STEM blended and flipped classrooms. We discuss our course delivery, data collection, and statistical analysis methods, followed by a comparison of the final exam results for flipped versus blended instruction for all students and various demographic groups. We provide a comparison of the methods in terms of the classroom environment and present students' perceptions of the flipped classroom.

LITERATURE REVIEW

Background on Blended and Flipped Instruction

Blended learning was featured in an instructional redesign program by the Pew Charitable Trusts (Twigg, 2003; Garrison & Kanuka, 2004). The program challenged higher education to redesign its instruction using technology, including computer-based assessments, online discussion groups and learning communities, and online tutorials. Blended learning has been advocated or implemented in the engineering disciplines represented in this study (i.e., mechanical, civil and electrical engineering), in which online experiments, labs, simulations, and even entire programs for non-traditional students have been implemented (Cortizo et al., 2010; Restivo et al., 2009; Henning et al., 2007; Hu & Zhang, 2010; Dollár & Steif, 2009; Mendez & Gonzalez, 2010; Sell et al., 2012; Bohmer et al., 2013). Blended learning has also been implemented in courses that are foundational to numerical methods, including programming, using online automatic-feedback self-practice tools (El-Zein et al., 2009).

With flipped instruction, a recent survey of almost 1,100 faculty members showed their top motivations for using flipped instruction were to increase student engagement (79%) and improve learning (76%) (Bart, 2015). In another recent survey, 200 instructors indicated they teach in a flipped mode because it increases interaction with students, promotes flexibility, and increases student engagement (Herreid & Schiller, 2013). This is in agreement with other sources that describe flipped instruction as increasing interaction and collaboration (Bergmann & Sams, 2012; Rosenberg, 2013). The flipped classroom has been implemented previously in a numerical methods course, in which it was compared to traditional instruction (Bishop & Verleger, 2013; Bishop, 2013). However, since active learning is gaining recognition, studies that compare active or enhanced approaches, such as ours, should be undertaken, as in a biology course recently (Jensen et al., 2015). The flipped classroom has been implemented in other courses for mechanical, electrical, and civil engineers, who comprised our study. Mechanical engineering courses included design, statics and mechanics, and electronics instrumentation (Dollár & Steif, 2009; Steif & Dollár, 2012; Cavalli et al., 2014; Connor et al., 2014; Papadopoulos & Roman, 2010). Electrical engineering courses included signal processing and electromagnetics (Van Veen, 2013; Furse, 2011). In civil engineering, flipped courses in structural design and engineering economic analysis have been offered (Gross & Musselman, 2015; Lavelle et al., 2015). The flipped classroom has also been implemented in math and programming courses that serve as pre-requisites for numerical methods (McGivney-Burelle & Xue, 2013; Talbert, 2014; Love et al., 2014; Souza & Rodrigues, 2015; Lape et al., 2014).

Blended and Flipped Classrooms: Results from the Literature

In comparisons of blended and traditional learning, blended learning has exhibited success. In the first round of the Pew redesign projects, five of the ten projects reported improved outcomes, while four reported equivalent achievement (Twigg, 2003). A multiple-semester comparison of face-to-face, fully online, and blended instruction showed blended to have the highest success (i.e., percent earning at least a grade of "C") (Cavanagh, 2011).

Comparisons of flipped and traditional instruction in mechanical, electrical, and civil engineering courses have shown mixed results, as has our study. For example, on a final statics concept assessment, the flipped sections scored statistically higher than the traditional sections (Papadopoulos & Roman, 2010). However, in a mechanics of materials course, there was no significant difference on a common final between the flipped and traditional sections (Thomas & Philpot, 2012). Further, while 82% in a traditional numerical methods course at North Dakota earned a C or better, just 72% did so in the flipped section (Cavalli et al., 2014). In another numerical methods course, the test gains were statistically equivalent between flipped and traditional sections (Bishop, 2013). Further examples of the mixed nature of comparisons of flipped and traditional instruction in electrical, civil, and foundational engineering (e.g., programming) courses can be found in the literature (Van Veen, 2013; Furse, 2011; Gross & Musselman, 2015; Lavelle et al., 2015; Velegol et al., 2015; Souza & Rodrigues, 2015; Lape et al., 2014).

Interestingly, in the recent 1,100-member faculty survey, only one-half (55%) saw evidence of improved learning (Bart, 2015), which coincides with the mixed results discussed in the literature.

Student perceptions of the flipped classroom have likewise been mixed in the literature, as noted previously and as seen in our study (Bishop & Verleger, 2013). Only about half (54%) of the North Dakota students preferred the flipped format (Cavalli et al., 2014). Similarly, in a flipped electronics instrumentation course, only 56% had a preference for video versus traditional lectures (Connor et al., 2014). However, in the flipped signal processing course, fewer than 10% indicated a preference for the traditional lecture by the end (Van Veen, 2013). In the structural design course, there has been increasing preference for the flipped format with each semester (Gross & Musselman, 2015). However, in the engineering economy course, survey results have indicated an increasing dislike of the flipped structure over successive semesters (Lavelle et al., 2015).

In contrast, students have generally had positive perceptions of blended learning in engineering. In a course that used a remote experiment, the students rated "deeper learning of previous knowledge" at 5.6 and "e-learning contribution for better learning quality" at 5.7 on the seven-point scale (Restivo et al., 2009). With a remote lab in a microcontrollers/robotics course, students could repeat experiments anywhere and anytime (i.e., 81% agreed) and felt more at ease than in a classical experimental environment (i.e., 66% agreed) (Sell et al., 2012). In the introductory programming course, satisfaction with the course rose 23% after implementation of the self-practice tool (El-Zein et al., 2009).

METHODOLOGY

Data from eight sections of the numerical methods course, which were taught over a period of two years at three institutions, were collected. Four were flipped sections, and four were blended sections. ASU and AAMU conducted one blended and one flipped section each over approximately a one-year period, and USF conducted two flipped and two blended sections over an approximately two-year period. Numerical methods course is taken primarily by the following engineering disciplines at each school: mechanical (USF), chemical and civil/environmental (ASU), and electrical/computer (AAMU). It covers numerical methods for differentiation, nonlinear equations, simultaneous linear equations, interpolation, regression, integration, and ordinary differential equations.

To compare our methods, a comprehensive assessment plan consisting of direct and indirect measures was applied. We used scores from common final exams to directly compare achievement for students as a whole as well as URMs, females, community college transfers, and Pell Grant recipients. The student's GPA, based on self-reported grades from the pre-requisite courses, was used as a covariate, or control variable, in the analysis. The free-response questions differed among the schools due to the varying majors, for in order to test higher-order skills, the instructors had to cater to physical applications within the discipline. The research team member serving as the assessment analyst also conducted pre and post-flip interviews with the instructors. In addition, the students were indirectly assessed for their perceptions of the benefits and drawbacks of flipped instruction using classroom environment and evaluation surveys, and focus groups. We will first discuss the methods used to develop and deliver the courses.

Course Delivery Methods and Student Participants

The delivery of the course was kept very similar across the institutions. Table 1 provides a description of the implementation at USF; the implementations at ASU and AAMU were very similar, with any notable differences explained below. The blended version involved in-class lecture and clicker quizzes to assess concepts. This coincides with the supplemental blended model, which retains the structure of the traditional class but adds technology (Twigg, 2003). After class, there were online auto-graded quizzes, problem sets, and programming projects. The Piazza online discussion board was available continuously for quick feedback from the instructor, TA, and students.

In the flipped version, students prepared before class with videos or readings, online auto-graded quizzes, and an essay response about the most difficult or interesting concepts. At ASU, students also completed auto-graded, coding practice examples using MATLAB's Cody Coursework before class. In addition, at all three schools, Piazza was used in the flipped classroom, and during class, clickers and micro-lectures based on the pre-class quiz and essay were employed. Also, students worked on exercises or problems with their peers, and the instructor was available for support. After class, students took online, auto-graded quizzes and completed programming projects and possibly problem sets.

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Table 1. *Comparison of Blended & Flipped Delivery Methods in this Study*

Activity	Blended	Flipped
Pre-class	Study pre-requisite material via videos for one-half of the course topics. Continuous access to open courseware & Piazza discussion board.	Study topic via textbook or video lectures. Continuous access to open courseware & Piazza discussion board. Automatically graded quiz (due 3 hours before class). Essay question on most difficult or interesting concept from the topic (due 3 hours before class).
In-class	Clicker quiz in half of class sessions to gauge conceptual understanding (no/low stakes). Fewer questions presented vs. in the flipped class. 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 (no/low stakes). 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. 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. Graded programming projects analyzing experimental data. Some in-class exercises assigned as homework; some graded.

The videos were created during previous NSF-funded open courseware development known as Holistic Numerical Methods (Kaw et al., 2012; Kaw & Yalcin, 2012; Owens et al., 2012; Kaw & Garapati, 2011; Kaw et al., 2004). The videos can be accessed at http://mathforcollege.com/nm/videos/index.html (HNM, 2015). Finally, the instructors' goals in flipping their courses are shown in Table 2.

In total, there were 273 enrolled in the blended and 233 enrolled in the flipped sections, for 506 total students between 2014 and 2016. The percentages of enrolled students for whom we had both final exam and demographic data to perform our analysis were as follows: for the flipped classes, 75%, 78%, and 85% at USF, ASU, and AAMU, respectively; and for the blended classes, 73%, 93%, and 72%, respectively. In total, there were 215 students in the blended classes and 180 students in the flipped classes for whom we had both final exam and demographic data for analysis. Our sample covered sophomores through seniors in multiple engineering disciplines, with approximately 21% female. Additional demographic characteristics can be determined based on the sample sizes in Table 9.

Table 2. *Instructor Goals with Flipping*

USF	Promote higher-order Bloom's skills, metacognitive skills, and responsibility for learning
ASU	Improve learning, in particular, programming confidence and skills Conduct hands-on activities with questions and answers in a low-stress environment Introduce in-class group work on formulation of problems
AAMU	Improve programming-skills, with attention to detail and real-world implementation Introduce in-class project and hands-on work

Assessment of Learning

Direct assessment of learning based upon the final exam was used to investigate our first research question comparing achievement with blended versus flipped instruction. The final exam contained 14 multiple-choice questions that were identical across the schools and instructional methods. The multiple-choice questions tested 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 semester to semester for each school, although they varied among the schools. These were intended to measure the higher-level skills.

Using the multiple-choice and free-response results, we compared the methods using an analysis of covariance (ANCOVA), with the pre-requisite GPA as the covariate or control variable. This was done for each school as well as the combined data. We analyzed the data in a stratified fashion, comparing the methods for those demographic segments of interest. For example, we were interested in questions such as: "For females, which method is associated with the best outcomes?" Given this granularity, the sample sizes were sometimes small, reducing power to detect statistically significant results (Ellis, 2010). Given the small samples for some of our comparisons, we also ran the non-parametric version of ANCOVA, 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 with small sample sizes. These analyses were conducted using SPSS 21. The pre-requisite GPA was based on self-reported grades from calculus 1/2/3, ordinary differential equations, introductory programming, physics 1, and/or linear algebra, depending on the school. The calculus courses covered differential, integral, and 3D vector calculus as well as series and sequences.

Because of the large number of statistical tests for each set of data, we applied Bonferroni's correction (Perneger, 1998; Bland & Altman, 1995). When a large number of tests are conducted, some will, unfortunately, result in $p < 0.05$ just by chance (McDonald, 2014). With Bonferroni's correction, the α-level for each individual test is set at $0.05/m$, where m is the number of tests run. Alternatively, the observed p-value can be adjusted by multiplying it by the number of tests run and comparing this to $\alpha = 0.05$, as was done in this study. This correction has the disadvantage that the interpretation of a result is dependent on the number of other tests run (Perneger, 1998). We present this information so the reader will be informed when interpreting our results. We also calculated effect sizes based on Cohen's d (Sullivan & Feinn, 2012; Kotrlik et al., 2011). The effect size is a measure of practical or substantive significance. As discussed in the articles above, the *p*-value and the effect size should both be reported in order to depict the complete picture. A prominent publication manual also advises to include both the *p*-value and the effect size (American Psychological Association, 2010). We used Cohen's thresholds to identify small, medium, and large effect sizes, respectively: d=0.20, d=0.50, and d=0.80 (Cohen, 1987; Salkind, 2010). For adjusted means, we calculated adjusted effect sizes (Huck, 2012). SPSS adjusts the means using the mean of the covariate (Norusis, 2005).

To directly assess achievement in a stratified manner, we developed a demographics survey, to be used in conjunction with the final exam. It consisted of questions regarding gender, race/ethnicity, Pell grant status, transfer status, and grades in pre-requisite courses, which were used to calculate a pre-requisite GPA to be used as a control variable. The students were asked to provide a personal code when completing this survey, which allowed us to match the student's final exam performance with his/her demographic characteristics. The demographic segments of particular interest within our research were the following:

1. Underrepresented minority (URM): {yes, no}
2. Pell Grant recipient: {yes, no}
3. Transfer status: {admitted to engineering as freshmen, transferred to engineering from a community college with an Associate's degree, other transfer students}
4. Gender: {male, female}

The underrepresented minority students consisted of Hispanic, American Indian, Black/African American, or Hawaiian/Pacific Islander students. The "other" transfer students consisted of internal 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 (Federal Pell Grant Program, 2015).

Classroom Environment Survey

We used the College and University Classroom Environment Inventory (CUCEI) to investigate our second research question about perceptions of the learning environment with blended versus flipped instruction (Fraser & Treagust, 1986). This reliable inventory evaluates seven psychosocial dimensions of the classroom, as shown in Table 3, and has been used previously in flipped classroom research (Strayer, 2012; Clark et al., 2014a). Several of the dimensions are typical goals of the flipped classroom, including student cohesiveness, individualization, innovation, involvement, and personalization. There are seven questions per dimension on a 1 to 5 scale, with 5 being most desirable. An average score for the dimension was calculated for each student, which was used to test for differences by dimension. Specifically, we ran an independent samples t-test for each dimension. In the case of one school, the sample sizes were small, so we ran the non-parametric Mann-Whitney test also (Norusis, 2005). We distributed the CUCEI during the last week of class and collected the data anonymously to enable the most comprehensive and honest viewpoints.

Table 3. *CUCEI Dimensions*

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

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. We employed many of the questions used by Zappe, Leicht and colleagues, who used perception surveys in a flipped engineering course (Zappe et al., 2009; Leicht et al., 2012). In addition, we expanded upon their questions given our specific interests. A complete copy of our survey can be found in an earlier publication (Clark et al., 2016a). 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, drawbacks, and suggestions regarding the flipped classroom. Two coders were involved in the content analysis of the responses. For the responses related to benefits, 40% were double-coded to provide a measure of inter-rater reliability. One of the coders was the assessment analyst for the project and the other was an upper level engineering student. The inter-rater reliability based on Cohen's Kappa was κ = 0.76, which suggests strong agreement beyond chance (Norusis, 2005). Our coding scheme in Table 4 was developed using a grounded, emergent qualitative analysis with support from the literature as part of prior flipped classroom research (Neuendorf, 2002; Clark et al., 2016b; Clark et al., 2014b). Each category was defined and described in our coding scheme/codebook, as shown in Table 4.

The benefits categories in Table 4 are discussed in the literature as objectives, outcomes, or characteristics of active, interactive, and engagement-focused learning environments, and this literature informed and supported our coding scheme. The following goals, results, and characteristics are discussed in this literature: content mastery, improved learning and outcomes, supplemental electronic communications for learning, and use of videos for review and final exam study (*Enhanced Learning or Learning Processes*); in-class problem-solving, teamwork, and verbal interaction among instructors and peers (*Alternative Use of Class Time*); self-paced, flexible, and segmented learning (*Video/Online Learning*); and motivation, engagement, study habits, and individual control of learning (*Preparation, Engagement & Professional Behaviors*) (Novak et al., 1999; Howard, 2015; Herreid & Schiller, 2013; Bart 2015; Connor et al., 2014; Furse, 2011). Explanations for lack of student preference for flipped instruction are even discussed in this literature (*No Benefit or Neutral*). For example, online video lectures do not enable instructor-to-student interaction like live lectures do (Howard, 2015).

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Table 4. *Coding Scheme for Open-Ended Benefits Question*

Benefits Category	Description/Examples
Alternative Use of Class Time	In-class active learning, problem-solving, and use of clickers; in-class support and questions; in-class group work and peer interactivity and support
Enhanced Learning or Learning Processes	Better understanding; enhanced learning or effectiveness; less confusion; multiple resources for learning, including discussion boards; reinforcement and review; multiple attempts
No Benefit or Neutral Result	No benefits perceived; dislike of flipped instruction; videos not used or instructional differences not noted
Preparation, Engagement & Professional Behaviors	Engagement during or enjoyment of class; prepared for class; independent learning; motivation for learning; accountability
Video/Online Learning	Re-watching and pausing of videos; own pace; flexibility and convenience; personal preferences; modularity of videos
Specific to the Course or its Videos	Videos relevant, helpful, or of high quality; videos concise, time-saving, or well-paced; videos contained demos or examples

The drawbacks/suggestion question was analyzed in the same manner, with 40% of the responses double-coded. The inter-rater reliability achieved was κ = 0.72, showing good agreement beyond chance (Norusis, 2005). The coding scheme, also developed during prior research, is shown in Table 5.

Likewise, discussions of the categories in Table 5 appear as suggestions, cautions, or findings throughout the literature on active, interactive, and engaged learning environments, and they also informed and supported our coding scheme. This literature suggests that a) attention be paid to motivational factors and grade incentives such as quizzes in active-learning environments, b) flipped instruction be introduced early in the college career, c) expectations for the flipped classroom be firmly established, and d) video lecture notes be provided (*Prepare, Equip & Incentivize*); in addition, instructional teams should contain adequate numbers to assist all students, and upfront mini-lectures may be necessary (*Class Time Usage*) (Novak et al., 1999; Mason et al., 2013; Herreid & Schiller, 2013; Leicht et al., 2012; Furse, 2011). The lack of interaction during a video – specifically the inability for students to ask questions and instructors to gauge student understanding - has been cautioned (*Inherent to Video Learning*) (Howard, 2015; Furse, 2011). Student resistance to the flipped classroom has been noted, including preferences for a partially-flipped classroom (*Approach Differently*) (Bart, 2015; Kecskemety & Morin, 2014; Leicht et al., 2012). Students have also reported videos as "challenging to learn from" (*Learning Decreased*) and as unexciting or requiring more examples (*Specific to the Course or its Videos*); in addition, insufficient time to watch them has been reported by students (Load, Burden, or Stressors) (Connor et al., 2014).

We also sought perspectives using focus groups in the flipped courses. Focus groups provide group-based qualitative information, which can be used with survey data for triangulation (Fitzpatrick, Sanders, & Worthen, 2011). We conducted two focus groups at approximately the three-fourths point in the semester, each consisting of a different demographic. One of the groups consisted of white males, and the other consisted of students *other than white males*, such as Hispanic, African American, or female students. This was consistent with our interest in considering underrepresented minorities and females. Given the nature of the three institutions, we had approximately two times as many student volunteers who were other than white males within our focus groups. We will discuss our survey and focus group results together for triangulation. In the focus groups, we asked questions about the benefits and disadvantages of the flipped classroom, including learning or professional growth, challenges or drawbacks, individualized support, and impact on programming skills.

Table 5. *Coding Scheme for Open-Ended Drawbacks/Suggestions Question*

Drawbacks/Suggestions Category	Description/Examples
Approach Differently	Do not flip courses – teach traditionally; lack of preference for flipped instruction; do not flip this particular course or flip only some class periods; offer a choice on flipping; do not switch styles during the semester (i.e., traditional to flipped)
Class Time Usage	Amount of in-class active learning, problem-solving, or content review/lecture; effectiveness of or motivational nature of in-class work; need for more instructor-types to assist during class; synchronize class with videos
Inherent to Video Learning	No questions during a video; instructor unable to assess understanding during a video; distractors to watching videos in a non-classroom setting; less motivation to attend class
Learning Decreased	Lesser student understanding or learning; difficulty learning from a video
Load, Burden, or Stressors	Increased workload or time required; insufficient time to complete out-of-class work; grade concerns; accountability quizzes; self-teaching
No Drawbacks or Neutral Result	No drawbacks or suggestions to offer
Prepare, Equip, & Incentivize Students	Prepare students for flipped instruction; incentivize or motivate students to watch videos; clarify/emphasize new expectations or rationale with flipping; ensure online materials available in advance; provide video "lecture" notes or index of topics; introduce flipping earlier in curriculum
Specific to the Course or its Videos	Videos required more or better examples/worked problems, greater detail, better labeling, or editing/bug fixes; videos were long, repetitive, dry, ill-paced, or too complex

Since our focus group questions aligned with the open-ended questions from our survey, we used the coding schemes in Tables 4 and 5 to analyze the focus group responses in a structured manner (Krueger, 1994). The same two coders coded all of the focus group data. Thus, the focus group responses were double-coded. Nonetheless, we calculated our first-time inter-rater reliability, which indicated fair to a good initial agreement. For the benefits coding, κ = 0.68, and for the drawbacks/suggestions coding, κ = 0.66.

In addition, to obtain instructor feedback and further triangulate our findings, the assessment analyst interviewed the instructors both before and after flipping their courses. She used a semi-structured interview protocol, with questions that aligned with the project's research goals and the instructors' individual goals (Boulmetis & Dutwin, 2011). The instructor interviews also served to highlight student gains and outcomes that may not have been apparent with the final exam results.

RESULTS

In this section, we provide a comparison of the direct assessment results for flipped versus blended instruction at the three institutions for various demographic segments. We also provide results from the perception measures, including the classroom environment and flipped-classroom evaluation surveys and focus groups, to address our second and third research questions.

Direct Assessment of Learning

Comparison of Multiple-Choice Results. For each school, we compared the multiple-choice results for all students and for the demographic segments of interest using the pre-requisite GPA as a control variable, as shown in Table 6. We also combined the multiple-choice data across the schools to compare the methods using the large dataset. The p-values based on the parametric and non-parametric analyses of covariance were generally in agreement. Given this and our tendency to default to the non-parametric analyses when the samples were small, we show only the non-parametric (i.e., Quade's Test) results for the individual schools. For the larger dataset, we present the parametric results. We provide two columns – one with the p-value prior to correction using Bonferroni's adjustment and the other after correction. The latter *p*-value was obtained by multiplying the former *p*-value by 5, since five demographics categories were tested. Also shown are the adjusted mean scores (out of 14 points).

At USF, the mean for the flipped method exceeded that for the blended method for four of the demographic categories, although the differences were not significant, and all effect sizes were small. Note that for our demographic categories with the individual schools, the sample sizes were small, reducing our power to detect statistically significant differences.

We found a similar result at ASU, in which the "flipped" multiple-choice mean also exceeded the "blended" mean for four demographic categories. Although the differences were not statistically significant, the effect size for Pell Grant recipients was approximately medium (d=0.49), suggesting a possible advantage to flipped instruction for this demographic. For the category in which the blended mean was higher (i.e., CC Transfers), the effect size was also approximately medium (d=0.46).

At AAMU, although the sample sizes were small, we found statistically significant differences and/or large effect sizes in favor of blended instruction, as shown in Table 8. Therefore, the

Table 6: *Multiple-Choice Questions – Comparison at USF*

Multiple-Choice USF (14 pts)	Flip	Blended	Quade's Test (pre-Bonferroni correction)	Quade's Test (with Bonferroni correction)	Cohen's Effect Size	Flip	Blended
	Adjusted Mean		***p***	***p***	***d***	**Sample Size**	
All	9.087	8.773	0.680	1.000	0.14	88	126
Female	8.300	9.025	0.229	1.000	-0.32	15	20
CC trans w/Assoc.	8.587	7.984	0.509	1.000	0.25	32	48
URM	9.169	8.777	0.743	1.000	0.20	33	25
Pell Grant recipient	9.256	8.773	0.489	1.000	0.21	29	46

Table 7: *Multiple-Choice Questions – Comparison at ASU*

Multiple-Choice ASU (14 pts)	Flip	Blended	Quade's Test (pre-Bonferroni correction)	Quade's Test (with Bonferroni correction)	Cohen's Effect Size	Flip	Blended
	Adjusted Mean		***p***	***p***	***d***	**Sample Size**	
All	7.138	6.954	0.605	1.000	0.08	69	76
Female	7.256	6.400	0.160	0.800	0.37	25	14
CC trans w/Assoc.	5.465	6.481	0.306	1.000	-0.46	9	10
URM	6.778	6.092	0.330	1.000	0.33	16	17
Pell Grant recipient	7.056	5.994	0.154	0.770	0.49	20	20

Table 8: *Multiple-Choice Questions – Comparison at AAMU*

Multiple-Choice AAMU (14 pts)	Flip	Blended	Quade's Test (pre-Bonferroni correction)	Quade's Test (with Bonferroni correction)	Cohen's Effect Size	Flip	Blended
	Adjusted Mean		***p***	***p***	***d***	**Sample Size**	
All	4.844	7.430	<0.0005	0.002	-1.55	23	13
Female	4.714	8.143	0.301	1.000	-1.88	5	3
CC trans w/Assoc.	7.309	7.346	-	-	-	1	2
URM	4.796	7.374	<0.0005	0.002	-1.50	22	12
Pell Grant recipient	4.188	7.341	0.002	0.008	-1.98	14	4

Table 9: *Multiple-Choice Questions – Three Schools Combined*

Multiple-Choice Three Schools (14 pts)	Flip	Blended	ANCOVA (pre-Bonferroni correction)	ANCOVA (with Bonferroni correction)	Cohen's Effect Size	Flip	Blended
	Adjusted Mean		***p***	***p***	***d***	**Sample Size**	
All	7.777	8.066	0.252	1.000	-0.12	180	215
Female	7.377	7.892	0.350	1.000	-0.21	45	37
CC trans w/Assoc.	7.790	7.780	0.984	1.000	0.00	42	60
URM	7.279	7.615	0.447	1.000	-0.14	71	54
Pell Grant recipient	7.484	7.850	0.421	1.000	-0.14	63	70

blended approach appeared to be better for lower-order skills at AAMU.

Upon combining the data for the three schools to create the more powerful dataset, we found that the blended mean exceeded the flipped mean for four demographic categories as shown in Table 9, although the differences were not statistically significant, and the effect sizes were small ($|d| \leq 0.21$). Given the larger sample, we present the parametric ANCOVA results; however, Quade's Test was in close agreement. Therefore, when considering all students in our study, there were small differences between blended and flipped instruction for lower-order skills, with blended instruction being slightly better.

Comparison of Free-response Results. The results of the free-response questions were analyzed similarly. Although we thought flipped instruction would emerge as the superior method with the free-response results due to the need to "dig deeper," we did not find statistically significant differences for any of the schools or with the combined data. At USF, the blended slightly exceeded the flipped mean for all demographic categories, with small effect sizes and non-significant differences (Table 10). Recall that for the multiple-choice questions, the flipped approach resulted in slightly higher scores at USF across most demographic categories.

At ASU, although the differences were not significant, the flipped exceeded the blended mean for the free-response results for all demographic categories (Table 11). In addition, the effect sizes associated with the CC Transfers and URM students were medium, and the effect size for the Pell grant recipients was close at $d=0.48$. Recall that the flipped approach was also slightly better at ASU for the multiple-choice questions.

At AAMU with the free-response questions, the blended exceeded the flipped mean for four demographic categories (Table 12). Although the sample sizes were small and the differences were not statistically significant, the effect size for the Pell grant recipients was large in favor of the blended approach ($|d|=0.84$).

With the free-response outcomes from the schools combined, the results were associated with small effect sizes ($|d| \leq 0.13$) and statistically non-significant results (Table 13). The free-response results were mixed in that the flipped scores were slightly higher for all students combined, females, and Pell grant recipients. However, for the CC Transfers and URM students, the blended scores were slightly higher.

Student Perceptions and Preferences

Classroom Environment Inventory. To investigate our second research question about perceptions of the learning environ-

Table 10: *Free-Response Questions – Comparison at USF*

Free-Response USF (14 pts)	Flip	Blended	Quade's Test (pre-Bonferroni correction)	Quade's Test (with Bonferroni correction)	Cohen's Effect Size	Flip	Blended
	Adjusted Mean		***p***	***p***	***d***	**Sample Size**	
All	5.894	6.281	0.298	1.000	-0.12	88	126
Female	6.426	7.031	0.420	1.000	-0.19	15	20
CC trans w/Assoc.	4.519	5.237	0.495	1.000	-0.24	32	48
URM	5.841	6.650	0.205	1.000	-0.27	33	25
Pell Grant recipient	5.597	6.385	0.243	1.000	-0.23	29	46

Table 11: *Free-Response Questions – Comparison at ASU*

Free-Response ASU (16 pts)	Flip	Blended	Quade's Test (pre-Bonferroni correction)	Quade's Test (with Bonferroni correction)	Cohen's Effect Size	Flip	Blended
	Adjusted Mean		***p***	***p***	***d***	**Sample Size**	
All	9.343	8.273	0.051	0.255	0.34	69	76
Female	9.324	8.715	0.595	1.000	0.20	25	14
CC trans w/Assoc.	8.423	6.919	0.281	1.000	0.58	9	10
URM	8.656	7.088	0.137	0.685	0.54	16	17
Pell Grant recipient	9.099	7.845	0.071	0.355	0.48	20	20

Table 12: *Free-Response Questions – Comparison at AAMU*

Free Response AAMU (16 pts)	Flip	Blended	Quade's Test (pre-Bonferroni correction)	Quade's Test (with Bonferroni correction)	Cohen's Effect Size	Flip	Blended
	Adjusted Mean		***p***	***p***	***d***	**Sample Size**	
All	8.658	9.759	0.738	1.000	-0.28	23	13
Female	10.921	10.132	0.762	1.000	0.18	5	3
CC trans w/Assoc.	7.383	10.309	-	-	-	1	2
URM	8.591	9.999	0.654	1.000	-0.35	22	12
Pell Grant recipient	8.379	11.175	0.167	0.668	-0.84	14	4

Table 13: *Free-Response Questions – Three Schools Combined*

Free Response Three Schools (16 pts)	Flip	Blended	ANCOVA (pre-Bonferroni correction)	ANCOVA (with Bonferroni correction)	Cohen's Effect Size	Flip	Blended
	Adjusted Mean		***p***	***p***	***d***	**Sample Size**	
All	7.565	7.199	0.298	1.000	0.11	23	13
Female	8.461	8.010	0.551	1.000	0.13	5	3
CC trans w/Assoc.	5.561	5.590	0.965	1.000	-0.01	1	2
URM	7.365	7.483	0.857	1.000	-0.03	22	12
Pell Grant recipient	7.403	7.007	0.521	1.000	0.11	14	4

ments, we used the College and University Classroom Environment Inventory (CUCEI). We obtained an average CUCEI response rate across the three schools of 77% (of the flipped classroom enrollment) and 80% (of the blended enrollment).

At USF, the mean for six of the seven CUCEI dimensions was higher in the blended classroom; of these six, five were significantly higher after Bonferroni's correction. These five are shown in the lower portion of Table 14 – innovation, involvement, personalization, satisfaction, and task orientation. Also, effect sizes were medium for the latter three. The perception of less organization in the flipped classroom is understandable, as students were expected to solve problems as the instructor circulated. It appears the USF students preferred the blended environment.

At ASU, the results were different, with the means for all dimensions higher in the flipped classroom. Two dimensions (i.e., involvement and personalization) were significantly higher after Bonferroni's correction (Table 16). These two dimensions are key goals of a flipped classroom. The effect was large for personalization and medium for involvement. The ASU students seemed to prefer the flipped environment. Interestingly, many of them had been introduced to the flipped format in two earlier courses, pointing to the potential benefit of a more institution-wide approach.

Similar to USF, the classroom environment clearly favored the blended approach at AAMU; however, the sample sizes were smaller at AAMU. This prompted the use of the non-parametric Mann Whitney test, although the t-test results compared closely. As shown in Table 16, the Satisfaction dimension was significantly higher in the blended classroom after applying the Bonferroni correction (p=0.028). In addition, the effect size was large (d=1.00), showing student preference for the blended format. Effect sizes were also large for Innovation and Task Orientation and medium for Involvement.

When the results were combined for the three schools, the Satisfaction and Task Orientation dimensions were associated with the most notable differences, with the blended classroom receiving higher scores for both. However, the effects were small ($|d| \leq 0.25$), and the differences were not significant with Bonferroni's correction. Across the schools, the Satisfaction dimension for the flipped classroom received a score of 3.06, just above the midpoint score of 3.00. The remaining dimensions were associated with non-significant differences and very small effect sizes ($|d|<0.13$).

Table 14: *Classroom Environment at USF*

USF (1-5 scale; 5 most desirable)		Flip	Blended	t-test (pre-Bonferroni correction)	t-test (with Bonferroni correction)	Cohen's Effect Size
		Dimension Mean		***p***	***p***	***d***
Cohesiveness	Students know & help one another	2.77	3.06	0.009	0.063	-0.37
Individualization	Treated individually or differentially	2.52	2.48	0.544	1.000	0.08
Innovation	Novel class activities or techniques	2.86	3.08	0.002	0.014	-0.44
Involvement	Active participation in class	3.18	3.41	0.008	0.056	-0.39
Personalization	Interaction w/ instructor	3.74	4.17	<0.0005	0.004	-0.62
Satisfaction	Enjoyment of classes	3.11	3.69	<0.0005	0.004	-0.63
Task Orientation	Organization of class activities	3.84	4.26	<0.0005	0.004	-0.74
	Sample Size	89	123			

Table 15: *Classroom Environment at ASU*

ASU (1-5 scale; 5 most desirable)		Flip	Blended	t-test (pre-Bonferroni correction)	t-test (with Bonferroni correction)	Cohen's Effect Size
		Dimension Mean		***p***	***p***	***d***
Cohesiveness	Students know & help one another	3.13	2.82	0.014	0.098	0.40
Individualization	Treated individually or differentially	2.60	2.52	0.324	1.000	0.16
Innovation	Novel class activities or techniques	2.89	2.70	0.014	0.098	0.40
Involvement	Active participation in class	3.33	2.91	<0.0005	0.004	0.70
Personalization	Interaction w/ instructor	4.07	3.42	<0.0005	0.004	0.83
Satisfaction	Enjoyment of classes	2.86	2.62	0.114	0.798	0.26
Task Orientation	Organization of class activities	3.84	3.58	0.012	0.084	0.41
	Sample Size	69	84			

Table 16: *Classroom Environment at AAMU*

AAMU (1-5 scale; 5 most desirable)		Flip	Blended	Mann Whitney (pre-Bonferroni correction)	Mann Whitney (with Bonferroni correction)	Cohen's Effect Size
		Dimension Mean		***p***	***p***	***d***
Cohesiveness	Students know & help one another	3.79	3.96	0.901	1.000	-0.23
Individualization	Treated individually or differentially	2.81	2.99	0.276	1.000	-0.40
Innovation	Novel class activities or techniques	3.05	3.42	0.011	0.077	-0.99
Involvement	Active participation in class	3.47	3.89	0.074	0.518	-0.73
Personalization	Interaction w/ instructor	4.07	4.31	0.157	1.000	-0.45
Satisfaction	Enjoyment of classes	3.49	4.33	0.004	0.028	-1.00
Task Orientation	Organization of class activities	3.96	4.40	0.011	0.077	-0.90
	Sample Size	22	12			

Flipped Classroom Evaluation Survey. The students evaluated the flipped classroom via survey, with approximately 75% of enrolled students responding. This survey, along with the focus groups, enabled us to investigate our third research question about the benefits and drawbacks of flipped instruction.

Results from the closed-ended questions are shown in Table 18. The USF and ASU students tended to have similar viewpoints about the flipped classroom. The AAMU students differed somewhat from them; however, there were fewer AAMU students. A large percentage at each school did not prefer the flipped classroom – 43% (USF), 54% (ASU), and 48% (AAMU). This coincides with the CUCEI Satisfaction score of 3.06 (out of 5.00) associated with the flipped classroom. Across the three schools, only 26% preferred flipped instruction. These percentages compare somewhat close to a school-wide initiative at another university, in which 27% indicated a preference and 36% indicated a non-preference for flipped instruction (Clark et al. 2016b). However, a large percentage at each school still preferred using class time for active learning. In comparison to our overall percentage of 54%, Zappe et al. similarly found that 48% agreed or strongly agreed that they preferred problem-solving to lecture during class (Zappe et al., 2009). This pattern of a lower preference for the flipped classroom compared to a greater preference for in-class active learning was identified previously (Bishop & Verleger, 2013). These instructors explained that students tend to prefer live to video lectures - but ultimately prefer activity to lecture.

In terms of effort and responsibilities with the flipped classroom, the majority of students felt the effort required was more or much more than in their other engineering courses – 74% (USF), 71% (ASU), and 59% (AAMU). The responsibility levels were also perceived as high. In a post-course interview, the USF instructor noted that most students (approximately two-thirds) took responsibility for their learning in the flipped classroom and arrived to class having studied the material; enhancing student responsibility was one of his goals with flipping. The ASU instructor noted in her interview that with the flipped classroom, students came to class with at least some idea of how to apply the numerical methods. About 34% overall identified the flipped classroom as a valuable experience from a career standpoint. Interestingly, the percentage at AAMU was higher at 52%. Approximately 38% overall were neutral on this.

The course discussion board was identified by a large percentage at USF and ASU as valuable to their learning – 51% and 68%, respectively. At AAMU, only 30% valued the discussion board. This was reiterated during the focus group when students explained that Piazza was unnecessary given the good interpersonal interaction during class. Many students admitted to not knowing how to begin the in-class problems – 54% (USF), 41% (ASU), and 43% (AAMU).

We asked the students about the benefits of flipped instruction in an open-ended question on the survey. Using the coding scheme in Table 4, we performed a content analysis of the responses. The percentage of respondents who identified each benefit is shown in Table 19. To our great satisfaction, enhanced learning or learning processes were the most or second-most frequently mentioned benefit at each school, identified by 41% of respondents overall. In her post-course interview, the ASU

Table 17: *Flipped Classroom Evaluation Survey – Closed Ended Questions*

Evaluation Survey Question	USF (n=84)	ASU (n=68)	AAMU (n=23)	Total (n=175)
1. Do you prefer a flipped classroom over the usual method of instruction in this class?				
Yes	29%	18%	43%	26%
No	43%	54%	48%	48%
Not Sure Yet	29%	28%	10%	26%
2. 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?				
Less or Much Less	10%	5%	23%	10%
About the Same	16%	23%	18%	20%
More or Much More	74%	71%	59%	71%
3. 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.				
Disagree or Strongly Disagree	16%	13%	13%	14%
Neutral	26%	42%	17%	31%
Agree or Strongly Agree	58%	46%	70%	54%
4. I often did NOT know how to begin solving the in-class problems assigned in the flipped classroom.				
Disagree or Strongly Disagree	25%	30%	26%	27%
Neutral	22%	29%	30%	25%
Agree or Strongly Agree	54%	41%	43%	48%
5. With the flipped classroom, how would you rate the responsibility placed on you, compared to the usual method of instruction in this class?				
Less or Much Less	4%	1%	9%	4%
About the Same	14%	18%	17%	16%
More or Much More	82%	81%	74%	80%
6. The flipped classroom enabled me to gain valuable experience for my future career.				
Disagree or Strongly Disagree	27%	30%	26%	28%
Neutral	39%	42%	22%	38%
Agree or Strongly Agree	34%	27%	52%	34%
7. I had greater learning gains with the flipped classroom versus the usual method of instruction in this class.				
Disagree or Strongly Disagree	38%	41%	35%	38%
Neutral	34%	27%	22%	30%
Agree or Strongly Agree	28%	32%	43%	31%
8. The ability to learn from and assist my fellow students in the flipped classroom was a valuable learning outcome for me.				
Disagree or Strongly Disagree	34%	26%	26%	30%
Neutral	29%	29%	22%	28%
Agree or Strongly Agree	37%	45%	52%	42%
9. The course discussion board was a valuable component of my learning.				
Disagree or Strongly Disagree	25%	11%	48%	23%
Neutral	24%	21%	22%	23%
Agree or Strongly Agree	51%	68%	30%	55%

instructor saw a noticeable improvement in the students' programming skills in the flipped classroom, in which they worked on group MATLAB projects inside and outside of class. Specifically, she noticed an improvement in the selection of the correct MATLAB commands, debugging, and use of Help documentation. During class, she was able to circulate and help students with their coding. Prior to class, students prepared by using MATLAB's Cody Coursework.

Next, in combined frequency, 34% identified preparation, engagement, and promotion of professional behaviors. In a post-course interview, the USF instructor identified life-long learning skills as a benefit of his flipped classroom, in which he aimed to prepare students for independent learning as future employed engineers. He wanted to prepare students in using multiple resources. In her post-course interview, the ASU instructor noted that the flipped classroom provided motivation for students to work consistently; else, they would get behind. In addition, the AAMU instructor noted the flipped classroom motivated some students to get ahead with the material; some even wanted more online quizzes. Thus, one-third to almost one-half of the respondents perceived the top benefits we were hoping to achieve – enhanced learning and engagement/responsibility. Nearly one-quarter overall (23%) liked the alternative use of class time, including problem-solving and instructor support.

The data about benefits gathered from the focus groups aligned well with the open-ended survey responses, in which the three most-frequently discussed benefits were the same as the top three in Table 18 (and in the same order). Analyzing by school, the top two benefits in Table 18 at USF were the top 2 benefits (in the same order) mentioned during their focus groups. For ASU, the top three benefits in Table 18 matched the top three discussed in their focus groups (in the same order). For AAMU, the top two benefits in Table 18 matched the top two discussed (in the same order). Overall, the focus groups noted the following top "specific" benefits: multiple resources for learning; class preparation, enhanced understanding, learning, or effectiveness; in-class support, motivation for learning, and independent learning. In line with this, the ASU instructor noted more activity and engagement during class, in particular questions and programming projects.

When comparing the focus group results of the two demographics, the top three benefits mentioned by each demographic were the same (although not in the same order) – enhanced learning/learning processes, preparation/engagement/professional, and alternative use of class time. Interestingly, the white males mentioned the benefit of enhanced learning/learning processes most frequently, while the students who were not white males mentioned preparation / engagement / professional most frequently.

Content Analysis of Suggestions and Drawbacks. We also asked students what drawbacks they perceived and their suggestions for the flipped classroom. We performed a second content analysis using the coding scheme in Table 5. The category identified by the largest percentage of respondents was class time usage, identified by 41% overall (Table 19). Both the USF and ASU instructors discussed that students wanted to be "taught" initially, including wanting to be "walked through" application of the numerical methods. This was followed by load, burden, or stressors with the flipped classroom (40% of respondents). The ASU instructor noted a large workload with the flipped classroom, including before and after-class accountability quizzes. Next in frequency, students suggested that the course be approached differently, such as not flipping it or flipping only portions. To our satisfaction, only 11% identified decreased learning in the flipped classroom.

Comparison with Focus Group Results. The drawbacks and suggestions gathered during the focus groups also aligned well with the open-ended survey responses. Analyzing by school, the two most-frequent drawbacks/suggestions at USF in Table 19 were the two most frequently mentioned in their focus groups. Load, burden, or stressors were most-frequently mentioned in ASU's focus groups, and it was the second-top category for ASU in Table 19. The top three drawbacks/suggestions for AAMU in Table 19 were also the top three mentioned in their focus group. Upon combining the responses, the top two categories in Table 19 were the top two mentioned in the focus groups. Specifically, the students noted stressors such as accountability quizzes, grade concerns, self-teaching, increased or excessive work or time, and insufficient time to complete assignments. When comparing the focus group responses of the two demographics, the two most-frequently mentioned categories were the same (and in the same order) – 1) load/burden/stressors, and 2) use of class time.

DISCUSSION OF RESULTS AND CONCLUSIONS

Blended and flipped approaches to teaching a numerical methods course for engineers were compared at three universities between 2014 and 2016. These teaching methods were compared in terms of final exam performance as well as classroom environment perceptions. his paper is believed to be one of the few such comparisons of active-learning-based approaches within engineering education.

We provided overall combined results as well as results in different settings (i.e., institutions). Considering our first research question about achievement, based on combining data from the schools, the blended instruction was slightly better for achievement with the multiple-choice (i.e., lower-order-skills) questions across multiple demographic groups. The differences were not statistically significant, and the effect sizes were small. However, for either USF or ASU individually, the flipped instruction was slightly better for multiple-choice performance, while at AAMU, there were large differences in favor of the blended approach. With the free-response (higher-order-skills) questions, the combined results were mixed, with slightly better results with blended instruction at USF and AAMU and the reverse at ASU. With the combined free-response data, none of the demographic-category differences were significant, and the effect sizes were small. As discussed in our literature review, other researchers have also found non-significant results when comparing flipped and non-flipped instruction.

Table 18: *Percentage of Respondents Identifying Benefits (Survey)*

Flipped Classroom Benefit	USF	ASU	AAMU	Total
Enhanced Learning or Learning Processes	41%	45%	32%	41%
Preparation, Engagement & Professional Behaviors	36%	30%	37%	34%
No Benefit or Neutral	20%	9%	11%	15%
Alternative Use of Class Time	16%	34%	16%	23%
Video/Online Learning	16%	4%	32%	13%
Specific to the Course or its Videos	5%	4%	5%	5%
Respondents	86	67	19	172

Relative to our second research question, the classroom environment results were more conclusive, in particular when examining the schools individually. At USF and AAMU, the blended classroom appeared to be the preferred environment. However, at ASU, the flipped classroom appeared to be the preferred environment. When combined, data from the three schools did not indicate a preferred environment. Interestingly, outcomes from the free-response questions aligned with classroom environment result for each of the schools individually – the blended approach was better (even if just slightly) for both outcomes at USF and AAMU, while the flipped approach was better at ASU.

Given the lack of significant differences in the final exam and classroom environment data, our results may indicate that with these two enhanced instructional approaches – flipped vs. blended instruction – there may not be a preferred or better approach based on research to date. Rather, it may be possible to use either approach with the expectation of similar outcomes in final exam scores or the perceived classroom environment. This may be the case if other enhanced or active methods are also compared in the same manner. This is an interesting research question that should continue to be studied. Therefore, we encourage the STEM education community to continue these types of comparisons, including additional studies of flipped vs. blended instruction. Our research and assessment methodology is rigorous and can be utilized by others for similar studies.

Regarding our third research question, students perceived both benefits and drawbacks with flipped instruction. Only 26% of all respondents preferred the flipped classroom, and 48% reported not preferring it. However, 54% overall stated a preference for solving problems in class versus listening to a lecture. The students overall tended to view the flipped classroom as demanding, with 71% reporting increased effort and 80% reporting increased responsibility. About half (i.e., 48%) said they did not know how to begin the in-class problems. In terms of greater learning or career gains, approximately 30-40% reported increased value with the flipped classroom across multiple questions, although 55% reported the discussion board as valuable.

Table 19: *Percentage of Respondents Identifying Drawbacks/Suggestions (Survey)*

Flipped Classroom Drawback/Suggestion	USF	ASU	AAMU	Total
Class Time Usage	38%	53%	6%	41%
Load, Burden, or Stressors	37%	50%	17%	40%
Approach Differently	19%	15%	11%	16%
Learning Decreased	15%	9%	0%	11%
No Drawbacks or Neutral	9%	3%	0%	6%
Specific to the Course or its Videos	9%	6%	28%	10%
Prepare, Equip, & Incentivize Students	8%	9%	17%	9%
Inherent to Video Learning	7%	2%	6%	5%
Respondents	86	66	18	170

Based on a content analysis of open-ended survey questions, the most frequent benefits of flipped instruction were 1) Enhanced learning or learning processes (41% of respondents); 2) Preparedness, engagement, and professional behaviors (34%); and 3) Alternative use of class time (23%). This was corroborated by the focus group results, in which the most-frequently discussed benefits were the same (and in the same order). The instructors corroborated these findings, identifying programming-skills enhancement, use of multiple resources, independent and life-long learning, motivation, career preparation, enhanced responsibility, and greater insight into students' struggles with an ability to address them during class. Thus, even though there were small differences between flipped and blended instruction in terms of combined final exam and classroom environment data, the students and instructors identified benefits with flipped instruction through multiple qualitative assessments. Conversely, the most frequently-stated drawbacks or suggestions pertained to the following: 1) Class time usage (41% of respondents); 2) Load, burden, or stressors (40%); and 3) Different approaches to the course (16%). The focus group results showed load/burden to be the most-frequently-discussed category, followed by class time usage and drawbacks or suggestions specific to the particular videos.

Study Limitations

Our study design was quasi-experimental, as are many educational studies since students were not randomly assigned to the classrooms. However, to account for a student's previous academic achievement, a likely confounding factor, we used the pre-requisite GPA as a control variable. The sample sizes for specific demographic segments within the individual schools were small, reducing power to detect significant differences. We used conservative statistical procedures (i.e., non-parametric tests and effect sizes) given these small samples. To increase the generalizability of our results, we included students from multiple engineering disciplines and university types.

Future Research and Directions

Our study contributes to the literature on blended versus flipped classrooms in STEM, and in particular numerical methods for engineering. We found only a small number of similar studies. As recently suggested, one study, or likely even a small number, on a pedagogical approach is insufficient to ensure confidence in future likely outcomes (Weimer, 2016 February). Thus, others who build upon our research and conclusions will further inform the STEM community. Thus, we recommend continuing to study these research questions with enhanced teaching methods, including for non-traditional and under-represented students, in particular at schools similar to AAMU.

In addition, despite greater demands perceived by students with the flipped classroom, they nonetheless identified longer-term benefits, including enhanced learning processes and professional preparation. Therefore, perhaps we should be assessing the impacts of flipped instruction into the future to obtain a more complete and comprehensive picture of its effectiveness. Related to this, we may wish to consider additional outcome variables (besides final exam scores) to better demonstrate significant direct gains with the flipped classroom, such as participation and involvement or longer-term undergraduate projects (Weimer, 2016 March 2). Our future investigations will include adaptive learning as part of the flipped experience. Similarly, enhancement of metacognitive skills was a goal of one of the instructors. Although we did not assess metacognitive skills, this may be a fruitful research topic, since reflection is a valuable component of engineering practice.

The second author, who is the instructor at USF, has extensive experience teaching this course in a blended manner (approximately 20 semesters). He prefers a semi-flipped approach, in which a portion of the topics is taught in a blended fashion, and a portion is taught in a flipped manner. He has noticed this approach allows more time to guide students through difficult problems and is less impacted by large class sizes. Both the ASU and AAMU instructors liked the flipped format and plan to use it going forward, with some modifications based on their experiences. However, as discussed by the USF instructor, deciding how to best teach numerical methods, even after years of doing so, continues to be an evolving process!

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REFERENCES

American Psychological Association. (2010). *Publication manual of the American psychological association* (6th ed.). Washington, DC: American Psychological Association, 32-34.

Astin, A. (1985). *Achieving educational excellence*. San Francisco, CA: Jossey-Bass, 133-136.

Bart, M. (2015, August 24). Flipped classroom survey highlights benefits and challenges. Retrieved from http://www.facultyfocus.com/topic/articles/blended-flipped-learning.

Bergmann, J., & Sams, A. (2012). *Flip your classroom: Reach every student in every class every day*. Eugene, OR: International Society for Technology in Education.

Bishop, J. (2013). A controlled study of the flipped classroom with numerical methods for engineers. (Doctoral dissertation). Retrieved from ProQuest Dissertations and Theses. (Publication No. 3606852)

Bishop, J., & Verleger, M. (2013). Testing the flipped classroom with model-eliciting activities and video lectures in a mid-level undergraduate engineering course. *Proceedings of the Frontiers in Education Conference*, IEEE, Seattle, WA, 161-163.

Bishop, J., & Verleger, M. (2013). The flipped classroom: A survey of the research. *Proceedings of the ASEE Annual Conference and Exposition*, Atlanta, GA.

Bland, J., & Altman, D. (1995). Multiple significance tests: The Bonferroni method. *BMJ,* 310, 170.

Bohmer, C., Roznawski, N., Meuth, H., & Beck-Meuth, E. (2013). Designing a blended-learning bachelor's degree in electrical engineering for non-traditional students. *Proceedings of the IEEE Global Engineering Education Conference (EDUCON),* Berlin, Germany, 924-927.

Bonwell, C., and Eison, J. (1991). Active learning: Creating excitement in the classroom. *ASHEERIC Higher Education Report No. 1*, George Washington University, Washington, DC.

Boulmetis, J., & Dutwin, P. (2011). *The ABCs of evaluation: Timeless techniques for program and project managers*. San Francisco, CA: John Wiley & Sons, Inc., 131.

Bourne, J., Harris, D., & Mayadas, F. (2005). Online engineering education: Learning anywhere, anytime. *Journal of Engineering Education*, 94(1), 131-146.

Carnegie Classification of Institutions of Higher Education. (2016). Retrieved from http://carnegieclassifications.iu.edu/lookup/lookup.php, last accessed March 2, 2016.

Carr, R., Palmer, S., & Hagel, P. (2015). Active learning: The importance of developing a comprehensive measure. *Active Learning in Higher Education*, 16(3), 173-186.

Cavalli, M., Neubert, J., McNally, D., & Jacklitch-Kuiken, D. (2014). Comparison of student performance and perceptions across multiple course delivery modes. *Proceedings of the ASEE Annual Conference and Exposition*, Indianapolis, IN.

Cavanagh, T. (2011). The blended learning toolkit: Improving student performance and retention. *Educause Quarterly Magazine,* 34(4).

Chi, M. (2009). Active-constructive-interactive: A conceptual framework for differentiating learning activities. *Topics in Cognitive Science,* 1(1), 73-105.

Clark, R., Kaw, A., & Besterfield-Sacre, M. (2016a). Comparing the effectiveness of blended, semi-flipped, and flipped formats in an engineering numerical methods course. *Advances in Engineering Education, 5*(3).

Clark, R., Besterfield-Sacre, M., Budny, D., Bursic, K., Clark, W., Norman, B., . . . & Slaughter, W. Flipping engineering courses: A school wide initiative. (2016b). *Advances in Engineering Education, 5*(3).

Clark, R., Norman, B., & Besterfield-Sacre, M. (2014a). Preliminary experiences with 'flipping' a facility layout/material handling course. *Proceedings of the Industrial and Systems Engineering Research Conference,* Montreal.

Clark, R., Budny, D., Bursic, K., & Besterfield-Sacre, M. (2014b). Preliminary experiences with "flipping" a freshman engineering programming course. *Proceedings of First Year Engineering Experience (FYEE) Conference,* College Station, TX.

Cohen, J. (1987). *Statistical power analysis for the behavioral sciences*. Hillsdale, NJ: Lawrence Erlbaum Associates, Inc., 24-27, 40.

Collins, A., Brown, J., & Newman, S. (1989). Cognitive apprenticeship: Teaching the crafts of reading, writing, and mathematics, In L. Resnick (Ed.), *Knowing, learning, and instruction: Essays in honor of Robert Glaser,* (453-494), Hillsdale, NJ: Lawrence Erlbaum Associates.

Connor, K., Newman, D., & Morris Deyoe, M. (2014). Flipping a classroom: A continual process of refinement. *Proceedings of the ASEE Annual Conference and Exposition*, Indianapolis, IN.

Cortizo, J., Rodríguez, E., Vijande, R., Sierra, J., & Noriega, A. (2010). Blended learning applied to the study of mechanical couplings in engineering. *Computers & Education*, 54(4), 1006-1019.

Dollár, A. & Steif, P. (2009). A web-based statics course used in an inverted classroom. *Proceedings of the ASEE Annual Conference and Exposition,* Austin, TX.

Dziuban, C., Hartman, J., Juge, F., Moskal, P., & Sorg, S. (2006). Blended learning enters the mainstream, In C. Bonk, & C. Graham (Eds.), *The handbook of blended learning: Global perspectives, local designs* (195-206), San Francisco, CA: John Wiley & Sons, Inc.

Ellis, P. (2010). *The essential guide to effect sizes: Statistical power, meta-analysis, and the interpretation of research results*. Cambridge: Cambridge University Press, 56-57.

El-Zein, A., Langrish, T., & Balaam, N. (2009). Blended teaching and learning of computer programming skills in engineering curricula. *Advances in Engineering Education*, 1(3), 1-18.

Federal Pell Grant Program. (2015). Retrieved from http://www2.ed.gov/programs/fpg/index.html, last accessed August 6, 2015.

Field, A. (2005). *Discovering statistics using SPSS*. London: SAGE Publications, 341.

Fitzpatrick, J., Sanders, J., & Worthen, B. (2011). *Program evaluation: Alternative approaches and practical guidelines*. Upper Saddle River, NJ: Pearson Education, Inc., 385-386, 437-438.

Fraser, B., & Treagust, D. (1986). Validity and use of an instrument for assessing classroom psychosocial environment in higher education. *Higher Education*, 15, 37-57.

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences*, 111(23), 1-6.

Furse, C. (2011). Lecture-free engineering education. *IEEE Antennas and Propagation Magazine*, 53(5), 176-179.

Garrison, D., & Vaughan, N. (2008). *Blended learning in higher education: Framework, principles, and guidelines*. San Francisco, CA: John Wiley & Sons, Inc., 4-8.

Garrison, D., & Kanuka, H. (2004). Blended learning: Uncovering its transformative potential in higher education. *The Internet and Higher Education*, 7(2), 95-105.

Graham, C. (2006). Blended learning systems: Definitions, current trends, and future directions, In C. Bonk, & C. Graham (Eds.), *The handbook of blended learning: Global perspectives, local designs* (3-21), San Francisco, CA: John Wiley & Sons, Inc.

Gross, S., & Musselman, E. (2015). Observations from three years of implementing an inverted (flipped) classroom approach in structural design courses. *Proceedings of the ASEE Annual Conference and Exposition*, Seattle, WA.

Hake, R. (1998). Interactive engagement vs. traditional methods: A six-thousand student survey of mechanics test data for introductory physics courses. *American Journal of Physics*, 66(1), 64-74.

Henning, K., Bornefeld, G., & Brall, S. (2007). Mechanical engineering at RWTH Aachen University: Professional curriculum development and teacher training. *European Journal of Engineering Education*, 32(4), 387-399.

Herreid, C., & Schiller, N. (2013). Case studies and the flipped classroom. *Journal of College Science Teaching*, 42(5), 62-66.

Howard, J. (2015). *Discussion in the college classroom – Getting your students engaged and participating in person*. San Francisco, CA: Jossey-Bass, 4-6, 108, 119.

Hu, Z., & Zhang, S. (2010). Blended/hybrid course design in active learning cloud at South Dakota State University. 2nd International Conference on Education Technology and Computer (ICETC), IEEE.

Huck, S. (2012). *Reading statistics and research*. Boston: Pearson Education, 361-362.

HNM: Holistic Numerical Methods (HNM) – Committed to Bringing Customized Numerical Methods to the Undergraduate. (2015). Retrieved from http://nm.MathForCollege.com, last accessed July 22, 2015.

Jensen, J., Kummer, T., & Godoy, P. (2015). Improvements from a flipped classroom may simply be the fruits of active learning. *CBE-Life Sciences Education*, 14, 1-12.

Kaw, A., Besterfield-Sacre, M., Scott, A., Lou, Y., & Pendyala, R. (2013). "Improving and assessing student learning in an inverted STEM classroom setting." NSF TUES-Type 2 Project, <http://nsf.gov/awardsearch/showAward?AWD_ID=1322586>, accessed May 28, 2015.

Kaw, A., & Hess, M. (2007). Comparing effectiveness of instructional delivery modalities in an engineering course. *International Journal of Engineering Education, 23*(3), 508-516.

Kaw, A., Yalcin, A., Lee-Thomas, G., Nguyen, D. T., Hess, M., Eison, J., & Owens, C. (2012). A holistic view on history, development, assessment, and future of an open courseware in numerical methods. *ASEE Computers in Education Journal 3*(4), 57-71.

Kaw, A., & Yalcin, A. (2012). Measuring student learning using initial and final concept test in a STEM course. *International Journal of Mathematical Education in Science and Technology, 43*(4), 435-448.

Kaw, A., & Garapati, S. (2011). Development and assessment of digital audiovisual YouTube lectures for an engineering course in numerical methods. *ASEE Computers in Education Journal, 21*(2), 89-97.

Kaw, A., Collier, N., Keteltas, M., Paul, J., & Besterfield, G. (2004). Holistic but customized resources for a course in numerical methods. *Computer Applications in Engineering Education, 11*(4), 203-210.

Kecskemety, K., & Morin, B. (2014). Student perceptions of inverted classroom benefits in a first-year engineering course. *Proceedings of the ASEE Annual Conference and Exposition*, Indianapolis, IN.

Kotrlik, J., Williams, H., & Jabor, M. (2011). Reporting and interpreting effect size in quantitative agricultural education research. *Journal of Agricultural Education*, 52(1), 132-142.

Krueger, R. (1994). *Focus groups: A practical guide for applied research*. Thousand Oaks, CA: SAGE Publications, 128.

Kuh, G., Kinzie, J., Schuh, J., & Whitt, E., & Associates. (2005). *Student success in college*. San Francisco, CA: Jossey-Bass, 7-9.

Lape, N., Levy, R., Yong, D., Haushalter, K., Eddy, R., & Hankel, N. (2014). Probing the inverted classroom: A controlled study of teaching and learning outcomes in undergraduate engineering and mathematics. *Proceedings of the ASEE Annual Conference and Exposition*, Indianapolis, IN.

Lavelle, J., Stimpson, M., & Brill, E. (2015). Evolution of a flipped engineering economy course. *Proceedings of the ASEE Annual Conference and Exposition*, Seattle, WA.

Lawson, A. (1983). Rank analysis of covariance: alternative approaches. *The Statistician*, 32(3), 331-337.

Leicht, R., Zappe, S., Litzinger, T., and Messner, J. (2012). Employing the classroom flip to move "lecture" out of the classroom. *Journal of Applications and Practices in Engineering Education*, 3(1).

Love, B., Hodge, A., Grandgenett, N., & Swift, A. (2014). Student learning and perceptions in a flipped linear algebra course. International *Journal of Mathematical Education in Science and Technology*, 45(3), 317-324.

Mason, G., Shuman, T., & Cook, K. (2013). Inverting (flipping) classrooms – advantages and challenges. *Proceedings of the ASEE Annual Conference and Exposition*, Atlanta, GA.

Mazur, E. (2009). Farewell, lecture? *Science*, 323, 50-51.

McDonald, J. (2014). *Handbook of biological statistics* (3rd ed.). Baltimore, MD: Sparky House Publishing, 254-260.

McGivney-Burelle, J., & Xue, F. (2013). Flipping calculus. *PRIMUS: Problems, Resources, and Issues in Mathematics Undergraduate Studies*, 23(5), 477-486.

Méndez, J., & González, E. (2010). A reactive blended learning proposal for an introductory control engineering course. *Computers & Education,* 54(4), 856-865.

Neuendorf, K. (2002). *The content analysis guidebook*. Thousand Oaks, CA: Sage Publications.

Norusis, M. (2005). *SPSS 14.0 statistical procedures companion*. Upper Saddle River, NJ: Prentice Hall, 152, 183.

Novak, G., Patterson, E., Gavrin, A., & Christian, W. (1999). *Just-in-time teaching: Blending active learning with web technology.* Upper Saddle River, NJ: Prentice Hall, xiv, 3-4, 9-10, 11-12, 25-26.

Osguthorpe, R., & Graham, C. (2003). Blended learning environments: Definitions and directions. *Quarterly Review of Distance Education*, 4(3), 227-233.

Owens, C., Kaw, A., & Hess, M. (2012). Assessing online resources for an engineering course in numerical methods. *Computer Applications in Engineering Education, 20*(3), 426-433.

Papadopoulos, C., & Roman, A. (2010). Implementing an inverted classroom model in engineering statics: Initial results. *Proceedings of the ASEE Annual Conference and Exposition*, Louisville, KY.

Pascarella, E. & Terenzini, P. (2005). *How college affects students*. San Francisco, CA: Jossey-Bass, 646.

Perneger, T. (1998). What's wrong with Bonferroni adjustments. *BMJ*, 316, 1236-1238.

Piazza: The Incredibly Easy, Completely Free Q&A Platform. (2015). Retrieved from https://piazza.com, last accessed September 24, 2015.

Prince, M. (2004). Does active learning work? A review of the research. *Journal of Engineering Education*, 93(3), 223-231.

Quade, D. (1967). Rank analysis of covariance. *Journal of the American Statistical Association*, 62(320), 1187-1200.

Restivo, M., Mendes, J., Lopes, A., Silva, C., & Chouzal, F. (2009). A remote laboratory in engineering measurement. *IEEE Transactions on Industrial Electronics*, 56(12), 4836-4843.

Rosenberg, T. (2013, October 23). In "flipped" classrooms, a method for mastery. *The New York Times*.

Salkind, N. (ed.). (2010). *Encyclopedia of research design*, vol. 1. Thousand Oaks, CA: Sage Publications.

Sell, R., Seiler, S., & Ptasik, D. (2012). Embedded system and robotic education in a blended learning environment utilizing remote and virtual labs in the cloud, accompanied by "robotic HomeLab kit." *International Journal of Emerging Technologies in Learning*, 7(4), 26-33.

Siemens, G. (2005). Connectivism: A learning theory for the digital age. *International Journal of Instructional Technology and Distance Learning*.

Souza, M., & Rodrigues, P. (2015). Investigating the effectiveness of the flipped classroom in an introductory programming course. *The New Educational Review*, 40(2), 129-139.

Steif, P. & Dollár, A. (2012). Relating usage of web-based learning materials to learning progress. *Proceedings of the ASEE Annual Conference and Exposition*, San Antonio, TX.

Strayer, J. (2012). How learning in an inverted classroom influences cooperation, innovation and task orientation. *Learning Environments Research*, 15(2), 171-193.

Sullivan, G., & Feinn, R. (2012). Using effect size–Or why the p value is not enough. *Journal of Graduate Medical Education*, 4(3), 279-282.

Talbert, R. (2014). Inverting the linear algebra classroom. *PRIMUS: Problems, Resources, and Issues in Mathematics Undergraduate Studies*, 24(5), 361-374.

Thomas, J., & Philpot, T. (2012). An inverted teaching model for a mechanics of materials course. *Proceedings of the ASEE Annual Conference and Exposition*, San Antonio, TX.

Twigg, C. (2003). Improving learning and reducing costs: New models for online learning. *Educause Review*, 38(5).

Twigg, C. (2003). Improving learning and reducing costs: Lessons learned from round I of the PEW grant program in course redesign. Center for Academic Transformation, Rensselaer Polytechnic Institute, Troy, NY.

Van Veen, B. (2013). Flipping signal-processing instruction. *IEEE Signal Processing Magazine*, 145-150.

Velegol, S., Zappe, S., & Mahoney, E. (2015). The evolution of a flipped classroom: Evidence-based recommendations. *Advances in Engineering Education*, 4(3).

Vygotsky, L. (1978). *Mind in society*. Cambridge, MA: Harvard University Press.

Weimer, M. (2016, February 17). Weighing the evidence of new instructional policies, practices, and behaviors. Retrieved from http://www.facultyfocus.com/articles/teaching-professor-blog/weighing-the-evidence-of-new-instructional-policies-practices-and-behaviors/.

Weimer, M. (2016, March 2). Clear criteria: A good way to improve participation. Retrieved from http://www.facultyfocus.com/articles/teaching-professor-blog/clear-criteria-a-good-way-to-improve-participation/.

Weimer, M. (2016, March 9). Active learning: In need of deeper exploration. Retrieved from http://www.facultyfocus.com/articles/teaching-professor-blog/active-learning-in-need-of-deeper-exploration/.

Wieman, C. (2014). Large-scale comparison of science teaching methods sends clear message. *Proceedings of the National Academy of Sciences*, 111(23), 8319-8320.

Wiggins, G., & McTighe, J. (2005). *Understanding by design.* Upper Saddle River, NJ: Pearson Education, Inc., 339-340.

Zappe, S., Leicht, R., Messner, J., Litzinger, T., and Lee, H. (2009). "Flipping" the classroom to explore active learning in a large undergraduate course. *Proceedings of the ASEE Annual Conference and Exposition*, Austin, TX.