Blended vs. Flipped Teaching: One Course - Three Engineering Schools

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Renee M. Clark serves as research assistant professor focusing on assessment and evaluation within the University of Pittsburgh's Swanson School of Engineering and its Engineering Education Research Center (EERC), where her interests focus on active and experiential learning. She has 25 years of experience as an engineer and analyst, having worked most recently for Walgreens and General Motors/Delphi Automotive in the areas of data analysis, IT, and manufacturing. She received her PhD in Industrial Engineering from the University of Pittsburgh and her MS in Mechanical Engineering from Case Western while working for Delphi. She completed her postdoctoral studies in engineering education at the University of Pittsburgh.

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Autar Kaw is a professor of mechanical engineering at the University of South Florida. He is a recipient of the 2012 U.S. Professor of the Year Award from the Council for Advancement and Support of Education and Carnegie Foundation for Advancement of Teaching. The award is the only national program to recognize excellence in undergraduate education.

Professor Kaw received his BE Honors degree in Mechanical Engineering from Birla Institute of Technology and Science (BITS) India in 1981, and his degrees of Ph.D. in 1987 and M.S. in 1984, both in Engineering Mechanics from Clemson University, SC. He joined the University of South Florida in 1987.

Professor Kaw's main scholarly interests are in engineering education research, adaptive learning, open courseware development, bascule bridge design, fracture mechanics, composite materials, and the state and future of higher education.

Funded by National Science Foundation (2002-16), under Professor Kaw's leadership, he and his colleagues from around the nation have developed, implemented, refined and assessed online resources for an open courseware in Numerical Methods (http://nm.MathForCollege.com). This courseware annually receives 1,000,000+ page views, 1,000,000+ views of the YouTube lectures, and 120,000+ visitors to the "numerical methods guy" blog.

Professor Kaw has written more than 85 refereed technical papers and his opinion editorials have appeared in the Tampa Bay Times, Tampa Tribune and Chronicle Vitae. His work has been covered/cited/quoted in many media outlets including Chronicle of Higher Education, Inside Higher Education, U.S. Congressional Record, Florida Senate Resolution, ASEE Prism, and Voice of America.

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Dr. Lou is very passionate about teaching and education research. In her teaching, she always emphasizes not just the "how" but also the "why" by providing background information on broader issues of the discipline and insights into theories and procedures. Dr. Lou has introduced active learning technologies (such as Clickers) to engage students more effectively during lectures and in-class examples. She also participated in a dissertation study about active learning in engineering disciplines when teaching at The University of Alabama.

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1. Introduction and Literature Review

With recent evidence showing that active learning is more effective than traditional lecture, educators have begun to call for comparisons among various active learning and enhanced instructional techniques, rather than continuing to use lecture as the comparison standard, in determining which techniques may be best for different content areas and demographic groups (Freeman et al., 2014; Wieman, 2014; Weimer, 2016). To this end, our study explores blended versus flipped instruction for an engineering numerical methods course.

Blended learning is a means to provide more engaging, quality-driven experiences by integrating or replacing portions of face-to-face with online or technology-enabled learning (Garrison & Vaughan, 2008; Bourne et. al, 2005; Dziuban et al., 2006). The flipped classroom uses class time for active learning or "doing," with students watching videos or completing readings beforehand (Bergmann & Sams, 2012). Flipped instruction was previously implemented in a numerical methods course, with no statistical differences found between the flipped and traditional sections on exams (Bishop, 2013). The flipped classroom has also been implemented in other courses for mechanical, electrical, and civil/environmental engineering students (who comprised our study), with mixed results in terms of achievement and student perceptions compared to traditional methods (Dollár & Steif, 2009; Steif & Dollár, 2012; Cavalli et al., 2014; Connor et al., 2014; Papadopoulos & Roman, 2010; Van Veen, 2013; Furse, 2011; Gross & Musselman, 2015; Lavelle et al., 2015; Velegol et al., 2015; Bishop & Verleger, 2013). Blended learning has likewise been advocated or implemented in mechanical and electrical engineering courses (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). Students have generally had positive perceptions of blended learning in engineering courses, as discussed in these articles.

For an engineering numerical methods course, our preliminary study with one university showed that standard examination results seemed to favor some degree of flipped instruction relative to blended instruction (Clark et al., 2016a). The present study incorporates two additional engineering schools to broaden the student demographic and is one of the few such STEM studies we are aware of. An NSF grant enabled us to compare blended and flipped instruction in a numerical methods course for engineers at three universities – University of South Florida (USF), Arizona State University (ASU), and Alabama A&M University (AAMU) - between 2014 and 2016 (Kaw et.al., 2013). These universities differ in their characteristics, thereby adding to the generalizability of our findings. At each school, the course covers basic numerical methods for differentiation, nonlinear equations, simultaneous linear equations, interpolation, regression, integration, and ordinary differential equations. The course is taken primarily by mechanical engineers at USF, chemical and civil/environmental engineers at ASU, and electrical/computer engineers at AAMU. Our research questions were:

1) Are there differences in achievement level for various demographic groups when using blended versus flipped instruction for numerical methods coursework at various undergraduate institutions?

2) Do students' perceptions of the learning environment differ with blended versus flipped instruction in numerical methods coursework at various undergraduate institutions?
3) What do students perceive as the benefits and drawbacks of flipped instruction with numerical methods coursework?

By addressing these questions, our goal is to develop recommended practices for teaching numerical methods and other STEM courses using active and/or technology-enhanced approaches. In the following sections, we will discuss our course design and delivery, data collection and analysis methods, and the results.

2. Methods – Course Delivery & Data Collection/Analysis

The delivery of the course was by design very similar across the schools. The blended version involved in-class clicker quizzes, lecture, post-class online auto-graded quizzes, problem sets, and programming projects. The Piazza online discussion board was available 24×7 for quick feedback (Piazza, 2015). In the flipped version, students prepared for class in advance with videos or readings, auto-graded quizzes, and an essay question about difficult or interesting concepts. The Piazza discussion board, clickers, and micro-lectures based on the pre-class responses were also employed. Students worked on short exercises or problems with their peers during class, and the instructor provided support. After class, students took online auto-graded quizzes and completed programming projects and problem sets. There were 215 students in the blended and 180 students in the flipped sections for whom we had exam and demographic data for analysis.

We used final exams and a demographics survey to directly compare blended versus flipped instruction, including for specific demographic groups. This exam contained 14 multiple-choice questions that were identical across the schools and instructional methods, and they measured lower-order skills. There were four free-response questions (intended to measure higher-order skills) that remained the same at each school regardless of the instructional method (but were slightly different from school to school). We compared the instructional methods via an analysis of covariance (ANCOVA), with the pre-requisite GPA serving as the control variable. This was done for each school as well as for the three schools combined. We analyzed the data in a stratified fashion, comparing the methods for various demographic groups of interest. Given this granularity, the sample sizes were sometimes small, reducing the power to detect statistically significant results (Ellis, 2010). Given the small samples for some comparisons, we defaulted to the non-parametric ANCOVA Quade's test results (Quade, 1967; Lawson, 1983). Because of the multiple statistical tests across the demographic groups, we applied Bonferroni's correction to the individual p-values (Perneger, 1998; Bland & Altman, 1995). We also calculated Cohen's d effect sizes as a measure of practical significance. A total of eight semesters of data was collected - four flipped and four blended. ASU and AAMU conducted one blended and one flipped semester each, and USF conducted two flipped and two blended semesters.

Furthermore, the assessment analyst conducted both pre- and post-flip interviews with the instructors, and student perceptions of flipped and blended instruction were assessed using classroom environment and evaluation surveys as well as focus groups. We used the College and University Classroom Environment Inventory (CUCEI) to investigate the classroom environment (Fraser & Treagust, 1986). Several of the CUCEI dimensions are objectives of the flipped classroom, including student cohesiveness, individualization, innovation, involvement, and personalization. An average score for each dimension was calculated for each student. These scores were then used to test for differences in flipped versus blended learning using independent samples *t*-tests and Bonferroni's correction. Our evaluation survey was modeled upon a previous survey and included both closed and open-ended questions (Zappe et al., 2009; Leicht et al., 2012). Two coders conducted the content analysis of the open-ended responses, in which 40% of the responses were double-coded to ensure inter-rater reliability. The inter-rater reliabilities were $\kappa = 0.72$ (drawbacks) and $\kappa = 0.76$ (benefits), suggesting good to strong agreement (Norusis, 2005). The coding schemes were developed as part of prior research using a grounded, emergent qualitative analysis of the students' responses with support from the literature (Neuendorf, 2002; Clark et al., 2016b). We also used these coding schemes to analyze the focus group responses in a structured manner (Krueger, 1994). The focus group responses were double-coded, with first time inter-rater reliabilities of $\kappa = 0.66$ (drawbacks/suggestions) and $\kappa = 0.68$ (benefits), indicating fair to good initial agreement.

3. Results and Conclusions

Upon combining the multiple-choice final exam data for the three schools to create the more powerful and meaningful dataset of all students, the *blended* mean exceeded the flipped mean for four of the five demographic categories (Table 1), although the differences were not statistically significant, and the effects were small ($|d| \leq 0.21$). The Bonferroni-corrected *p*-values were obtained by multiplying the initial *p*-value by 5 (up to a maximum value of 1.00), since five demographic categories were tested. Given the larger sample sizes with the combined data, we present the parametric ANCOVA results (vs. the non-parametric Quade's Test results).

Table 1: 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 students	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 Transfer 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

However, for either USF or ASU individually, flipped instruction was slightly (non-significantly) better for multiple-choice performance, while at AAMU, there were statistically significant differences and large effect sizes in favor of blended instruction. These results are detailed in Tables 2-4. With the free-response questions, there were slightly better results with blended instruction at USF and AAMU, and the reverse was true at ASU, although the differences were non-significant. With the combined free response data, the results were associated with small effect sizes ($|d| \leq 0.13$) and non-significant results also. The combined free response results were mixed in that the flipped scores were slightly higher for all students combined, females, and Pell grant recipients, whereas the blended scores were slightly higher for CC Transfers and URM students.

Table 2: 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 students	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 Transfer 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 3: 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 students	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 Transfer 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 4: 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 students	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 Transfer 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

The classroom environment results were more conclusive, particularly when examining the schools individually. At USF and AAMU, the blended classroom appeared to be the preferred learning environment. At USF, there were five significantly-higher dimensions and three medium effect sizes. At AAMU, where the sample sizes were smaller, there was one significantly-higher dimension, three large effect sizes, and one medium effect size. However, at ASU, the flipped classroom appeared to be the preferred environment, with two significantly-higher dimensions and one medium and one large effect size. When combined, data from the three schools did not indicate a preferred environment overall, with small effect sizes ($|d|\leq 0.25$) and non-significant differences. Interestingly, outcomes from the free-response questions aligned with the classroom environment results 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 for these outcomes at ASU. We obtained a CUCEI response rate across the schools of 77% (of flipped classroom enrollment) and 80% (of blended enrollment).

Students perceived both benefits and drawbacks with flipped instruction. Only 26% of survey respondents across the schools preferred the flipped classroom, and 48% reported *not* preferring it. However, 54% stated a preference for solving problems in class versus listening to lecture. The students overall tended to view the flipped classroom as demanding, with 71% reporting increased effort, 80% reporting increased responsibility expected, and about half (i.e., 48%) saying they did not know how to begin solving the in-class problems. In terms of greater learning or career gains, approximately 30-40% reported increased value with the flipped classroom across multiple survey questions, whereas 55% reported the discussion board was valuable for learning. Based on the open-ended questions, the most frequently-stated benefits of flipped instruction were 1) enhanced learning or learning processes (41% of all respondents); 2) preparation, engagement, and professional behaviors (34%); and 3) alternative use of class time (23%). This finding was corroborated by the focus group results, in which the three most-frequently discussed benefits were the same (and in the same order). When asked in their post-course interviews about the benefits of flipped instruction, the instructors also 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 the ability to address them during class). Thus, even though there were small differences with the combined exam and classroom environment data, the students and instructors identified benefits with flipped instruction through multiple qualitative assessments. The most frequent drawbacks or suggestions pertained to the following: 1) class time usage (41% of all respondents); 2) load, burden, or stressors (40%); and 3) taking different approaches to the course (16%). Load/burden was the most-frequently-discussed drawback or suggestion in the focus groups, followed by class time usage and drawbacks/suggestions specific to the particular videos.

Thus, despite greater demands perceived by the students with the flipped classroom, they nonetheless identified longer-term benefits, including enhanced learning processes and professional preparation. Therefore, should we be re-assessing the impacts of flipped instruction at a future time with our students? Related to this, should we consider additional outcome variables besides exam scores to better demonstrate significant gains with flipping? Our future investigations will include adaptive learning as part of the pre-class flipped experience.

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