BLENDED LEARNING IN PRACTICE

A Guide for Practitioners and Researchers

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BLENDED DYNAMICS—DOES SIZE MATTER?

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MIX Taxonomy Classification: This course is blended. It closely resembles a flipped course as students receive content online before class and receive feedback while applying content in class. In addition, the students receive feedback while applying content after class through an online quizzing system that gives them multiple chances to attempt problems, making the assessment more formative than summative.

Research Method Classification: The research method the instructor selected is a quasi-experimental design. The two experimental groups, one that had a medium class size and one that had a large class size, were separated by semester and had the same instructor. Student performance was measured through a concept inventory and course exams. Student perceptions were measured through an in-class survey, the institutional end-of-course survey, and an engagement survey.

INTRODUCTION

Blended learning has shown some preliminary success in STEM courses. Analyses of the pedagogy's effectiveness include studies on introductory chemistry and calculus courses (Eichler and Peeples, 2016; Scott et al., 2016).

Successful trials in engineering courses include Velegol et al. (2015), who, in an introductory course, found that students like the flexibility of the course format and enjoy the interaction with the instructor and other students during class time. In a blended introductory Dynamics course, Swithenbank and DeNucci (2014) found higher scores on a common final examination relative to that of a traditional course. Similarly, Webster et al. (2016) demonstrated gains in problem-solving skills and conceptual understanding via a blended classroom approach in an introductory Fluid Mechanics course. Experiments in blended learning with a Computational Fluid Dynamics course show that the collaborative learning environment successfully increased student satisfaction (Sauret and Hargreaves, 2015). While these and other examples suggest advantages of the blended classroom approach, there are outstanding questions to be addressed about effectively implementing the pedagogy in STEM courses, including the issue of the impact of class size on the intervention.

This study examines the influence of class size on blended classroom pedagogy in an engineering mechanics course. In this chapter, the term *blended* will be used to describe the course format (following the taxonomy described in Margulieux et al., 2016) and encompasses the approach that has also been described as a *flipped classroom*. In the blended classroom approach, the often passive activity of listening to and watching a lecture is replaced with technologically mediated material outside of the class meeting. In-class activities are designed to engage students and encourage active learning. As detailed below, the study finds that this format is highly effective as class size expands due to the pedagogy's emphasis on maintaining a student-centric approach that provides flexibility, learning support, and active engagement.

The benefits of a blended classroom include (1) more one-on-one time with students, (2) improved student attendance at lectures, (3) self-paced learning, (4) "just-in-time" instruction, (5) opportunities for active and collaborative learning, and (6) increased engagement. The latter two benefits may be the most important. When conceptually challenging material is being introduced, increasing student engagement can improve student learning (Smith et al., 2005). Stickel and Liu (2015) also noted that increased student engagement is a key component in the success of the blended engineering classroom.

Barriers to increasing engagement may be overcome by shifting to a student-centric approach (Catalano and Catalano, 1999). Further, active learning and in-class collaboration approaches generally foster student engagement and enhance student performance (Prince, 2004; Felder and Brent, 2004; Albers and Bottomley, 2011; Freeman et al., 2014). In particular, Velegol et al. (2015) noted that the blended classroom format allowed students to become active learners. Gains in performance were directly related to increased student engagement, knowledge retention, and skill development (Velegol et al., 2015).

Studies that quantitatively measure the effectiveness of a blended classroom intervention are sparse, however, because collaboration and engagement can be hard to measure. On this note, Hotle and Garrow (2016) reported that while the literature suggests the blended learning format increases student engagement and satisfaction, very few studies have been able to isolate the effect of the intervention and measure a significant increase in assessment metrics relative to a traditional lecture-based approach.

Class size is an important consideration in any format, but it is particularly of interest for blended classrooms due to the personalized aspects of the approach. It has been suggested that there are potential economic benefits to the blended classroom approach because more students may be added to the classroom while still effectively maintaining student flexibility and personalized contact with the instructor (Hotle and Garrow, 2016). The converse (i.e., increased cost) has also been suggested due to the increased workload and time commitment necessary to effectively deliver a student-centric pedagogy (Catalano and Catalano, 1999). Roach (2014) noted that higher student-instructor ratios may be tolerated if blended classroom approaches allow for more personalized instruction. The potential downside is that the benefits of the individualized interaction with the instructor may necessarily decrease simply due to the demands of a larger population of students.

Measuring the impact of engagement and collaboration, especially for larger classes, is an important direction for research on the effectiveness of blended learning. Inherent challenges of large-scale classes include spatial constraints in the typical lecture hall, high student-instructor ratios, and technological barriers, among other factors. It is generally unknown whether the benefits of blended learning, as well as the personalized instruction of the blended classroom pedagogy, scale to larger class sizes. In fact, Hotle and Garrow (2016) report that they are unaware of any previous study that examines the influence of class size on the effectiveness of the blended classroom approach. There is, however, evidence that the benefits of active learning can scale up to large classes (up to 100) in an introductory physics course (Beichner et al., 2007).

To examine the scalability of this instructional approach, the authors designed a study to quantitatively and qualitatively assess the impact of class size on student performance and attitudes in a second-year (i.e., sophomore) engineering Dynamics course. The study examined two classes where the substantial difference between the classes is the size of the student groups: 37 in one course and 82 in the other. This chapter compares these two classes, which were offered in different semesters by the same instructor who employed a nearly identical blended classroom approach.

DESCRIPTION OF THE PEDAGOGY

Dynamics is a required course in the civil engineering and environmental engineering degree programs at the Georgia Institute of Technology (Georgia Tech). The course is part of an engineering mechanics sequence in both degree programs and the prerequisite is engineering Statics. Specific topics covered in the course include kinematics, kinetics, work-energy methods, and impulse momentum methods for both particle and rigid body applications. This particular course is limited to two-dimensional rigid body analysis. In Georgia Tech's curriculum, the semester-long, two-credit-hour course is intended for the second semester of the second year in both the civil engineering and environmental engineering degree programs. Typical enrollees include a mix of second-year and third-year students plus a small number of fourth-year students. The course meets for 50 minutes of class time two days each week on a Monday-Wednesday schedule. The primary course learning outcome is that students demonstrate an ability to appropriately apply fundamental analysis techniques to engineering dynamics applications.

In the instructor's opinion, the traditional lecture-based course format was deficient in its ability to provide an environment in which students could consistently obtain a depth of understanding of the material and thereby gain confidence in a range of problem-solving exercises. In his observation of the traditional lecture-based approach, students passively listened even with significant effort on the instructor's part to encourage participation and discussion. Class attendance was mixed; some students consistently attended and others attended infrequently. Note that attendance in the traditional format was not formally recorded and did not directly enter into the grading scheme. The instructor suspected that a significant fraction of the students were parroting homework assignment solutions from internet sources or unauthorized archives maintained by student groups. Students received personalized support only if they self-identified a deficiency and visited the instructor's office for help. The net effect was ultimately weak collective performance on the examinations and a lack of evidence that students had mastered the material. While student feedback on the traditional lecture-based class format was generally positive about the course effectiveness, student feedback also indicated a less-than-effective learning environment with few opportunities to engage:

- "It seemed like class was spent furiously writing down notes, and then trying to make sense of it later when it came time to do homework."
- "Homework was often frustrating and very time-consuming, but amount of effort expected was appropriate."
- "In spite of lecture attendance I still often had a really hard time with the homework (but lecture was always fast and the time was spent effectively, so I'm not sure what else could be done)."
- "The exams were a lot harder than any of the notes or homework examples. And I could work through the notes and homeworks with ease but struggle on the test."

With these observations as a backdrop, the instructor transformed the course into a blended format with the goal of engaging students with the subject and enhancing problem-solving skills through active participation.

Blended Course Design

The blended classroom approach for the Dynamics course is described in the flowchart in figure 9.1. Students watched online lecture recordings before the class session. The lectures were recorded by the instructor via the Tegrity recording software (McGraw-Hill Higher Education, Burr Ridge, IL). The Professional Education Division at Georgia Tech provided technical support for the lecture recording process, including managing software and licenses, maintaining the servers, and answering questions and problem reports. Lectures were recorded in the instructor's campus office without an audience present. A tablet PC and webcam were used as the recording hardware. The Open-Sankoré software (http://etmantra.com/open-sankore-a-free-software-for-smart-board-or-interactive-board) was employed on the tablet PC to create

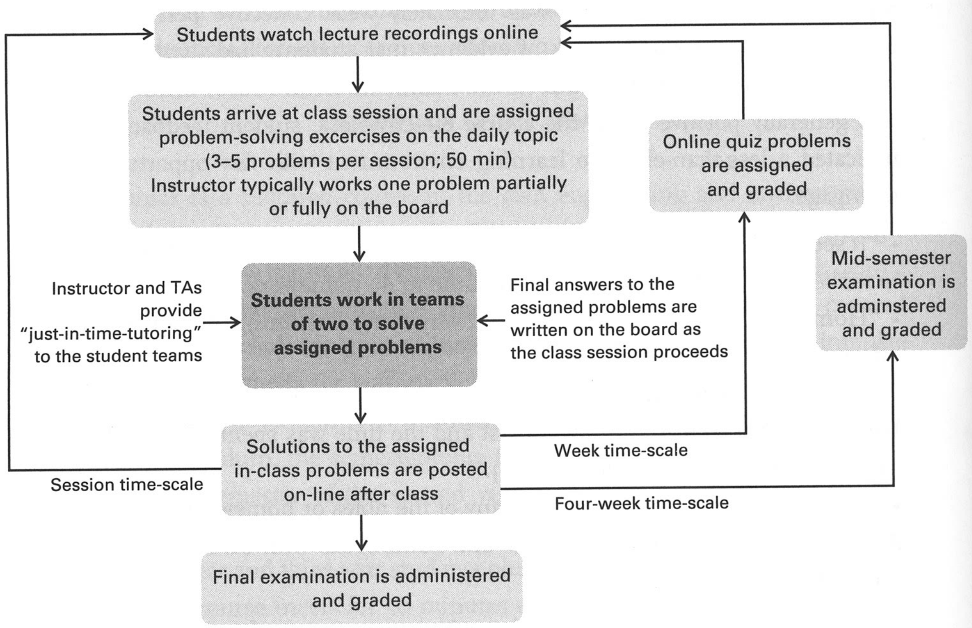

Figure 9.1
Description and sequence of the blended classroom format for the engineering Dynamics course

an electronic whiteboard. The instructor predominantly handwrote the lecture content on the electronic whiteboard using a stylus. The audio content and the instructor's face and upper torso were recorded using the webcam. Students had significant control during playback. Figure 9.2 shows a screenshot of an example lecture recording during playback. The main window displayed the electronic-whiteboard lecture content. Synchronously, the webcam recording was displayed in a smaller window. Students could expand the main window (i.e., the electronic whiteboard) to full screen, if desired. They also had the ability to make bookmarks and notes at key junctures as well as to pause, rewind, and fast-forward the recording. The playback speed could be set at normal and at up to two times faster.

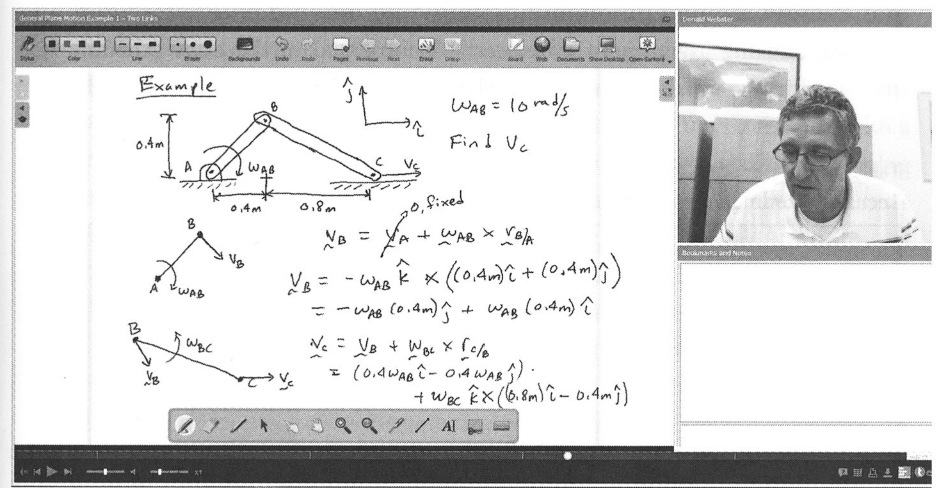

Figure 9.2
Screenshot of a lecture recording during playback. The largest window shows the electronic whiteboard created with the Open-Sankoré software. The lecture content was predominately handwritten with a stylus, as shown in this example. The synchronized webcam recording of the instructor is shown in a smaller window. Students may use the icons at the bottom left to control the playback, and they may make notes and bookmarks in the window at the bottom right.

Fifty-five to sixty-two short lecture recordings were created (table 9.1). The content followed that developed in previous live lectures during traditional lecture-based class offerings, with the significant difference that the content was presented in short and highly focused segments. The average lecture recording duration was slightly longer than 8 minutes (table 9.1). The content included both a theoretical introduction of the topics and examples of step-by-step problem solving. The pace of the lectures was brisk, but the progressively handwritten format facilitated students being able to follow along with note taking. In fact, students often took handwritten notes based on the lecture recordings just as they would in a live lecture. The seven recordings added for the spring 2015 semester were all sample problem-solving exercises, thereby increasing the number of example problems presented from 34 to 41 (table 9.1). Between zero and six lecture recordings were assigned prior to each class session, and the assignment was clearly documented in the class schedule (included in the syllabus) and on the class website. The class schedule in the

Table 9.1
Lecture recording and assignment information for each semester

	Fall 2013	Spring 2015
Number of lecture recordings	55	62
Number of example problems presented in lecture recordings	34	41
Average duration of the lecture recordings	8.3 minutes	8.2 minutes
Number of in-class problems assigned	76	82
Number of TAs	2 (one undergraduate and one graduate student)	3 (all graduate students)
Student-teacher ratio	12.3: 1	20.5: 1
Number of online quiz assignments	12	11
Aggregate number of online quiz problems	48	44

syllabus also stated the relevant section(s) of the course textbook (Meriam and Kraige, 2012) for the particular daily topic.

The primary focus of the in-class activities was to develop problem-solving skills and proficiency, which was addressed via assignments that required active participation. During the class sessions (two 50-minute sessions each week), students worked in teams of two to solve assigned problems addressing the session topic. The team size of two was selected to avoid situations where a student was left out of the conversation by being the third (or worse) wheel. Students selected their partner during the first week of the semester and the teams remained together for the full semester. The teaming process was constrained by forming four groups of students and instructing the students to select a partner from within the same subpopulation. The groups were created by ranking the students' incoming GPA (without informing them of the criterion) with the objective of forming teams consisting of students with comparable previous academic performance. The purpose was to prevent a more accomplished student from dominating the interaction with a less accomplished student. Concerns about partnering two weaker-performing students were alleviated by providing in-class support to the teams, as described below.

Up to five problem-solving exercises were assigned during each class session. The number of problems depended on the scope and complexity of the problems, which also were typically sequenced in terms of difficulty. The assigned problems consisted of homework-style problems from textbooks, examination problems from previous semesters, and problems written by the instructor. To create a collaborative space for students to interact, personalized whiteboards (81 cm × 53 cm) were provided to each team along with markers and erasers. The teams were not required to use the collaborative boards and their use diminished as the semester proceeded because the students often preferred to write on their individual assignment sheets. The total number of in-class problems assigned over the course of the semester was between 76 and 82 (table 9.1), and the added problems in the second semester were for sessions in which the majority of student teams finished early or to fill a noted topical gap. The subject of the problems for each session was directly linked to the session topic and the assigned lecture recordings. The instructor typically started the class session by working one of the problems on the board (either partially or fully) to refresh the topic of the lecture recordings, to allow the students to ask questions, and to get the students quickly engaged in problem-solving.

As a session proceeded, student teams worked on the remaining problems at their respective stations. The instructor and teaching assistants (TAs) roamed the room to answer student questions, pose questions to students, and discuss issues such as application relevance. The interaction could be described as "just-in-time tutoring" since questions typically came at the point in the problem-solving analysis at which the student teams were stuck or confused. As most instructors can appreciate, the student teams were highly receptive to the explanations of the instructor and TAs at that moment since they had reached a barrier to progressing with the analysis and realized that they needed help. It is important to note that this interaction was more "messy" than a traditional lecture in which the instructor is controlling the content and pace of the session; students were making mistakes, getting confused, asking questions, and working past challenges. In the blended classroom, the teams were working at their unique pace and controlling the sequence of exercises on which they worked. In the instructor's opinion, it is important to allow this flexibility, variation, and messiness to flourish because it ultimately provides a unique and tailored learning experience for each student.

The student teams demonstrated a broad range of performance. Teams that entered with a strong understanding of the material could complete the entire set of problems rapidly and thereby gain fluency by repetitive problem solving. Alternatively, teams that struggled with the material would typically ask numerous questions and might only finish one problem during the session. The benefit to those students was gaining basic skills and knowledge of the topic. In this way, the course format met students at their level of understanding and provided a framework for every student to learn and progress. The benefit to the instructor was to gain an understanding of where individual students were struggling and where they were excelling in order to guide future presentations and discussions.

The final answers to the problems were written on the board as the session continued to enable students to check their results. After the class session, the instructor's handwritten solutions to the problems were posted on the class website. Student teams that did not complete the full set of problems were given the opportunity to finish the problems and compare their work to the instructor's solutions. No credit was given for performance on the in-class problems. Instead, attendance was recorded and students who missed two or fewer sessions during the semester were rewarded with an additional 10% toward their final grade. This policy contrasted with that for the traditional lecture-based format, described above, in which attendance was not recorded and did not factor directly into the students' final grade. In practice, this policy had the effect of strongly encouraging attendance and participation in the class sessions, with only a small number of students failing to earn the attendance credit. In the instructor's opinion, the lack of graded credit for the in-class problems was a key factor in the success of the course. Students were free to work at their own pace rather than rush and stress out about getting all the problems completed. The approach created an environment in which they could make mistakes and ask questions without penalty.

To assess comprehension, online quizzes were assigned each week, with quiz problems selected to be topically consistent with the problems previously worked in class. The WileyPlus online system was used in connection with the textbook employed (Meriam and Kraige, 2012). Once the problem was assigned, each student received a unique set of input parameters. Hence, the system required them to perform the analysis and calculations for their unique set of numbers. Students were allowed to make three attempts at the solution with immediate feedback on the correctness of their submission. In the event that they did not correctly answer the problem by the third attempt, they gained access to the published solution to the problem in PDF file format (with a standard set of parameter values). Scores on the online quizzes were recorded and incorporated into the students' final grade in the course. The number of quizzes was 11 or 12, and the total number of quiz problems was between 44 and 48 (table 9.1).

Another key aspect of the course success was that it possessed an organized structure such that students could easily find the needed links and materials at the correct moment in the semester. The motivation was to create a simple and intuitive organization that would eliminate frustrating student searches for material and instead allow them to focus on learning the course subject. The class website, together with the schedule published in the syllabus, facilitated the organizational structure. Folders on the website were created for each class session and named by the respective date of the session. All links and materials for the session were included there, including links to all assigned lecture recordings, the assigned in-class problems for the session, and (after class) the solutions to the in-class problems. Links to the online quiz assignments were also created in the folders corresponding to the due date. By following the website folder structure, students could chronologically complete the assignments without ambiguity.

Three midsemester examinations (roughly four weeks apart) and a final examination provided the primary assessments of student achievement. The examinations consisted of problem-solving exercises that were manually graded by the instructor. Examinations were graded based on the students' demonstrated ability to (1) identify an effective approach to the problem-solving exercises, (2) set up the problem-solving technique including a sketch, if needed, (3) correctly apply the principle(s) for the analysis, and (4) perform the calculations to produce the solution.

STUDY DESIGN AND ASSESSMENT

Comparing the two blended classroom implementations of the Dynamics course, the substantial difference is that in the fall 2013 class the student count was 37, whereas in the spring 2015 class it was 82. The instructor was consistent across the classes, and the approach was nearly identical. Two TAs were employed in the classroom of the smaller class, leading to a student-teacher ratio of 12.3 to 1 (table 9.1). A higher student-teacher ratio (20.5 to 1) was present in the classroom of the larger class, which had three TAs (table 9.1). Note that the two individuals employed as TAs in fall 2013 were also

employed in spring 2015. A few additional minor differences are noted above and summarized in table 9.1. The number of lecture recordings increased from 55 to 62 in the second offering of the course, due to the instructor's desire to increase the number of example problems presented. The number of in-class problems increased slightly from 76 to 82, largely due to the need to add problems to sessions in which the majority of students completed the assignment early. Due to slight differences in the calendar for the fall and spring semesters, 12 quizzes were assigned in fall 2013 for a total of 48 quiz problems, and 11 quizzes were assigned in spring 2015 for a total of 44 quiz problems (table 9.1).

It also should be noted that the classroom environments were substantially different (figure 9.3). The smaller fall 2013 class was in a general-purpose classroom that seats up to 66. The chairs rolled easily on casters over the carpet. The tables were designed for two students to sit comfortably and they could be moved if necessary (although not on casters). The instructor and TAs could easily move between the table rows in the classroom. In contrast, the larger spring 2015 class was in a tiered lecture hall since it was the only room with sufficient size for the class (with a capacity of 95 students). The chairs were again on casters, but the tables extended the full length of the rows and were fixed to the floor. The spacing between neighboring tables was limited, which hindered the instructor's and TAs' movement to the center of the rows. The restricted movement had the potential to limit the just-in-time tutoring interactions. The instructor attempted to limit these adverse effects by purposely walking through the rows periodically to interact with student groups along the entire row. This typically required maneuvering awkwardly around the furniture and stepping over backpacks and other items on the floor. Student groups often asked questions as the instructor passed close by, which suggested the proximity of the instructor encouraged their willingness to ask for help. Hence, the purposeful effort to walk between the rows was beneficial despite the awkwardness. The whiteboard and audiovisual equipment had been recently installed in both rooms and were equivalent (and modern).

The Dynamics Concept Inventory (DCI) Assessment Test was administered twice during the class to assess conceptual gains from the intervention. This

Figures 9.3a–b
Images of the classrooms. The first image shows the general-purpose classroom used for the fall 2013 class, and the second image shows the gently tiered lecture hall used for the spring 2015 class.

is a validated instrument designed to evaluate student learning and curricular innovations (Gray et al., 2005). It consists of 29 questions with multiple-choice answers that require minimal computation. The DCI was selected for this study due to the fact that its conceptual nature allows administration pre- and postsemester for subsequent comparison of student gains. It was administered during the first week of the semester and again during the last session of the semester. The DCI was not announced in advance on either occasion in either class and was administered by a neutral third party. It is important to note that the instructor did not review the content of the assessment test in advance.

Figures 9.3a–b (continued).

The instructor employed an identical final examination in each class. It consisted of five problem-solving exercises that comprehensively covered the full semester of course material. The examinations were hand-graded by the instructor using the same rubric (i.e., scoring guide to evaluate the quality of students' constructed responses).

To assess engagement and student response to the format, during the 11th week of the semester, students in both classes were asked to anonymously complete a survey (handwritten; administered in class) to provide feedback on their perceptions of the course format. The survey included the following questions:

- What aspects of the blended classroom format do you prefer over a traditional-style course?

- What aspects of a traditional-style course do you prefer over the blended classroom format?
- Do you find the lecture recordings to be helpful? More or less so than a traditional classroom lecture?
- At what moment in the class did you feel most engaged with what was happening?
- At what moment in the class did you feel most distanced from what was happening?
- Would you recommend this course format to a friend?

Students were asked to complete an engagement survey, using questions from the National Survey of Student Engagement (Center for Postsecondary Research, 2012). The survey covered 14 questions about student collaboration, skill development, and the use of higher-order thinking skills. Students were asked how often they performed certain tasks, such as how often they worked with other students on projects during class time, and responses were given using the following scale: never, occasionally, often, or very often.

During the final three weeks of the semester (including final examination week), students submitted the online Course-Instructor-Opinion-Survey (institute-administered) on a voluntary and anonymous basis.

RESULTS

Data were available for 37 students who completed the fall 2013 course and 82 students who completed the spring 2015 course. Crosstabulating students' major, gender, and year in school by the semester during which they took the course (fall 2013 or spring 2015) yielded fairly consistent results between the two classes (table 9.2). The fall 2013 class was 68% male, whereas the spring 2015 class was 55% male, but this difference is not statistically significant. In fall 2013, 68% of the students were civil engineering majors and 30% were environmental engineering majors. In spring 2015, 78% of the students were civil engineering majors and 22% were environmental engineering majors. These differences, too, were not statistically significant. However, the two groups did

Table 9.2
Student demographic information by semester taken

			Semester		
			Fall 2013	Spring 2015	Total
Gender	Female	*N*	12	37	49
		% w/in semester	32.4%	45.1%	41.2%
	Male	*N*	25	45	70
		% w/in semester	67.6%	54.9%	58.8%
Major	Civil engineering	*N*	25	64	89
		% w/in semester	67.6%	78.1%	74.8%
	Environmental engineering	*N*	11	18	29
		% w/in semester	29.7%	22.0%	24.4%
	Architecture	*N*	1	0	1
		% w/in semester	2.7%	0%	0.8%
Year	2nd year	*N*	19	22	41
		% w/in semester	51.4%	26.8%	34.5%
	3rd year	*N*	13	52	65
		% w/in semester	35.1%	63.4%	54.6%
	4th year	*N*	5	8	14
		% w/in semester	13.5%	9.8%	11.8%
Total		*N*	37	82	119

differ on one factor: the year in school (second, third, or fourth year). Table 9.2 shows that the majority of the fall 2013 students (51%) were second-year students compared with the spring 2015 students, where the majority (62%) were third-year students. However, this difference was not enough to warrant tests for nonnormally distributed data in the analyses that follow.

Table 9.3 shows that there were no statistically significant differences in the students' previous academic preparation and performance. Incoming GPA differed by only 0.04 points (table 9.3). The average total number of semester credit hours that students had completed prior to taking the course differed

Table 9.3
Prior academic performance for two student groups

	Semester	*N*	Mean	Standard deviation	Standard error mean	*t* (*p*-value)
Incoming GPA	Fall 2013	37	3.02	0.63	0.10	0.253 (0.80)
	Spring 2015	81	2.98	0.70	0.08	
Total number of credit hours completed prior to course	Fall 2013	37	67.7	17.6	2.9	-0.644 (0.52)
	Spring 2015	81	69.8	15.6	1.7	
Number of credit hours completed at Georgia Tech prior to course	Fall 2013	37	42.2	21.2	3.5	-0.490 (0.62)
	Spring 2015	81	44.2	21.2	2.4	

by only 2.1 hours, and the average total number of semester credit hours that students had completed specifically at Georgia Tech prior to taking the course differed by only 2 hours (table 9.3).

Student Performance

Table 9.4 shows consistent average results on the presemester DCI (a mean of 8.8 points in fall 2013 compared with a mean of 9.0 points in spring 2015) and on the postsemester DCI (a mean of 10.6 points in fall 2013 compared with 10.5 points in spring 2015). *T*-tests of the differences between means yielded no significant differences between the two classes, lending support to the suggestion that the blended classroom model employed in both classes was equally effective regardless of class size. Furthermore, the effect size of the difference in presemester DCI mean scores, measured by the Cohen effect-size parameter, *d*, was 0.06. According to Cohen (1988), effect sizes can be classified as small where $d = 0.2$, medium where $d = 0.5$, and large where $d = 0.8$. Therefore, an effect-size parameter seen here of 0.06 indicates a practically nonexistent difference between the two groups of students. The effect size (*d*) of the difference in postsemester DCI mean scores was 0.03 (table 9.4). Again, this shows practically no difference between the two classes.

Table 9.4
Comparison of presemester and postsemester Dynamics Concept Inventory (DCI) Assessment Test scores and final examination scores

	Semester	*N*	Mean	Standard deviation	Standard error mean	Cohen effect-size parameter, *d*
Presemester DCI score	Fall 2013	37	8.8	3.2	0.52	0.06
	Spring 2015	82	9.0	3.9	0.43	
Postsemester DCI score	Fall 2013	36	10.6	3.9	0.65	0.03
	Spring 2015	65	10.5	4.9	0.61	
Final exam score	Fall 2013	36	76.9	14.9	2.5	0.25
	Spring 2015	82	80.2	13.0	1.4	

The scores on the DCI (both pre- and postsemester) were considered by the instructor to be fairly low, however. Note that the largest mean score reported of 10.6 (table 9.4) corresponds to 36.6% of the 29 problems answered correctly. A subsequent examination of the topics covered on the DCI revealed that 4 of the 11 topics included on the assessment test were not covered in this two-credit-hour course, and at least one additional topic was addressed in a limited manner (recall that the instructor did not review the DCI in advance to prevent "teaching to the test"). Since the DCI covered topics that the designers selected due to common misperceptions among students and since the course content didn't address a significant fraction of the exam content, it is not surprising in hindsight to have relatively low average scores on the assessment test (for both semesters and for both pre- and postsemester).

The pre/post differences on the DCI administered within each class were significant, however (see figure 9.4). The gain in students' conceptual understanding between the pre- and postsemester DCIs is consistent with the results of Webster et al. (2016) in a blended classroom format for a Fluid Mechanics course. Thirty-five students completed both the pre- and postsemester DCI in fall 2013, showing means of 8.9 and 10.7, pre- to postsemester, respectively, a difference of 1.8 points. A paired-samples *t*-test yielded a *t*-value of 3.60,

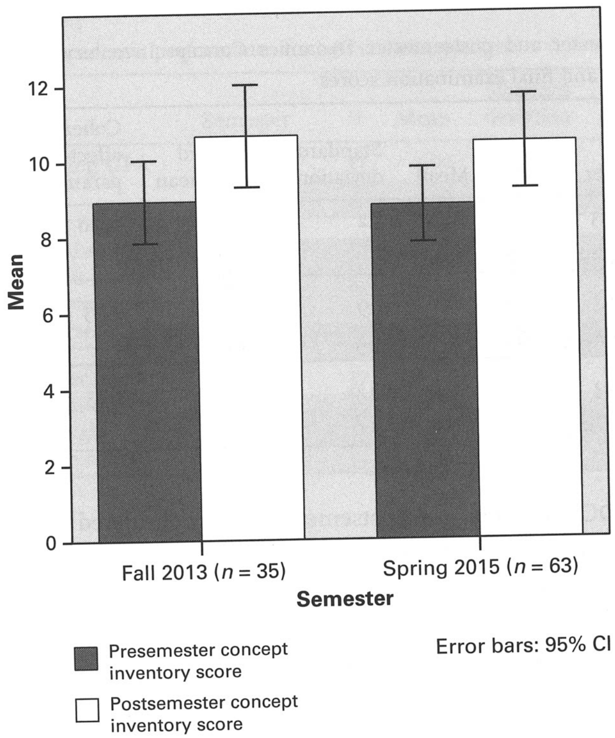

Figure 9.4
Comparison of presemester and postsemester Dynamics Concept Inventory (DCI) Assessment Test scores. The bars report mean values and the error bars report 95% confidence intervals.

significant at $p = 0.001$, and the Cohen effect-size parameter, d, was 0.53, measuring a medium effect of the course from the beginning to the end. In spring 2015, 63 students completed both the pre- and postsemester DCI, showing means of 8.8 and 10.5, pre- to postsemester, respectively, a difference of 1.7 points. A paired-samples t-test yielded a t-value of 3.83, significant at $p < 0.001$, and the Cohen effect-size parameter, d, was 0.35, a small-to-medium effect of the course from the beginning to the end.

One notable difference between classes is the average final examination score: 76.9 in fall 2013 and 80.2 in spring 2015 (table 9.4). This 3.3-point difference is not statistically significant, but it does show a small Cohen effect-size parameter of $d = 0.25$. The fact that students in the larger class (spring 2015) scored higher on the final examination than students in the smaller class does not indicate that the blended class model is less effective in larger classes. In this case, the opposite is true—students in a larger blended class slightly outperformed students in a smaller blended class.

In sum, within-class gains in conceptual ability across the semester were statistically significant and had small-to-medium effect sizes. But between-class differences were not significant, supporting our hypothesis that the blended classroom model was equally effective in both classes regardless of the size of the class. Students also demonstrated good problem-solving ability on the final examination, and the average score on the common examination was actually higher in the larger class.

Student Feedback

Fourteen questions from the National Survey of Student Engagement were used to establish collaboration, skill development, and the use of higher-order thinking skills. Survey responses were crosstabulated between the fall 2013 and spring 2015 classes, and chi-square tests established whether differences between the two classes were statistically significant. Responses to 12 of these questions indicated no significant difference between the classes, including:

During your class, about how often have you done each of the following?
- Worked with other students on projects during class time
- Tutored or taught the class materials to other students in the class

To what extent has this course emphasized the mental activities listed below?
- Memorizing facts, ideas, or methods from your course and readings so you can repeat them in almost the same form
- Analyzing the basic elements of an idea, experience, or theory such as examining a specific case or situation in depth and considering its components

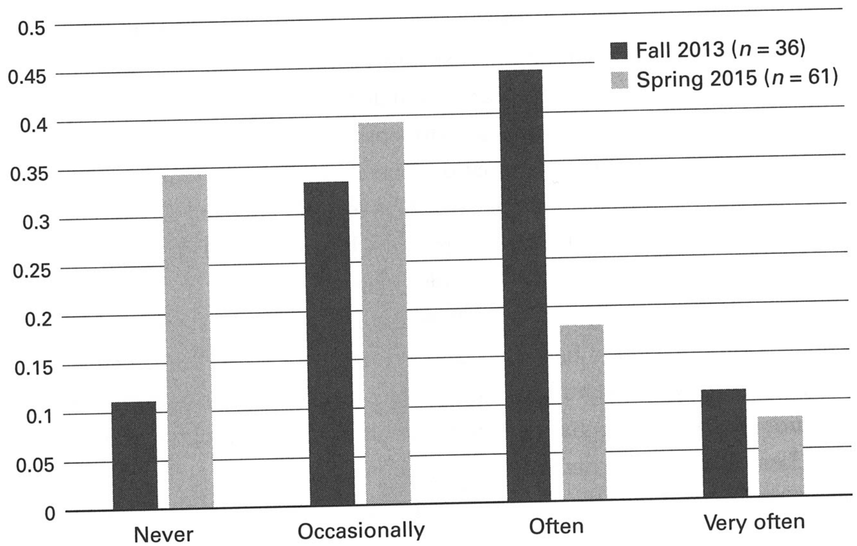

Figure 9.5
Histogram of student responses to the question "About how often have you asked questions during class or contributed to class discussion?" Data reported as fraction of students for the respective semester. Chi-square test results: $\chi^2 = 10.88$, $p < 0.012$, which reveals the distributions are not statistically similar.

- Synthesizing and organizing ideas, information, or experiences into new, more complicated interpretations and relationships
- Evaluating the value of information, arguments, or methods, such as examining how others gathered and interpreted data and assessing the accuracy of their conclusions
- Applying theories and/or concepts to practical problems or in new situations

To what extent has this course contributed to your knowledge, skills, and personal development in the following ways?
- Acquiring job- or career-related knowledge and skills
- Writing clearly, accurately, and effectively
- Thinking critically and/or analytically

- Learning effectively on your own, so you can identify, research, and complete a given task
- Working effectively with other individuals

Figures 9.5 and 9.6 show the results for the responses to the two questions that revealed a significant difference between the two classes:

During your class, about how often have you done each of the following?
- Asked questions during class or contributed to class discussion (figure 9.5)
- Worked with classmates outside of class to complete class assignments (figure 9.6)

It is proposed that the differences between classes with respect to students' likelihood to ask questions during class may have been due to class size

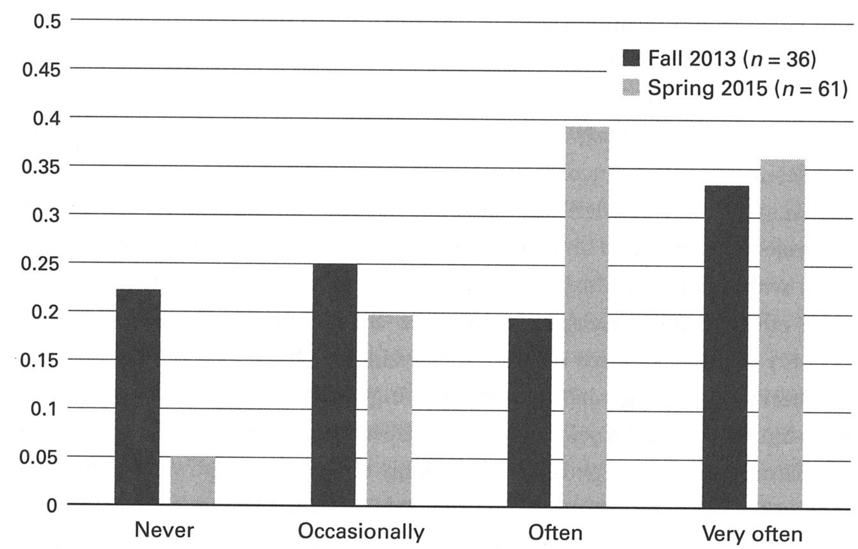

Figure 9.6
Histogram of student responses to the question "About how often have you worked with classmates outside of class to complete class assignments?" Data reported as fraction of students for the respective semester. Chi-square test results: $\chi^2 = 9.13$, $p < 0.028$, which reveals the distributions are not statistically similar.

and interpretation of the question. In both classes, students regularly asked questions of the instructor and TAs when working in pairs or small groups. However, if one perceives the question to refer to "asking a question while the whole class is listening," then figure 9.5 would indicate that students in the larger class may be less likely to ask a question while the instructor is at the front of the classroom interacting with the entire class. Since the class format, assignments, and process for selecting teams were the same in the classes, explanations for the differences in figure 9.6 are less clear. It is possible that more experience or maturity or previously developed friendships led to increased collaboration outside of class, since the demographics of the larger spring 2015 class included more third-year students and fewer second-year students (table 9.2). Based on the 12 similar responses and the potential explanations for the two queries yielding different responses, it is concluded that students in the larger class are reporting a level of engagement similar to the level experienced by their counterparts in the smaller class.

The results of the National Survey of Student Engagement also indicate that the course format was highly effective in engaging students and producing the desired learning outcomes. For instance, 90.5% of students (across both sections) responded "often" or "very often" about working with other students on projects during class time and 81.4% responded similarly for working effectively with other individuals. This provides evidence that the in-class activities were effective at encouraging students to collaborate. Similarly, the "often" or "very often" responses regarding analyzing the basic elements of an idea, synthesizing and organizing ideas, applying theories, and thinking critically were 84.5%, 78.4%, 88.7%, and 89.5%, respectively. These results suggest that the blended classroom pedagogy was highly effective at empowering students with engineering problem-solving skills, which is the primary course learning outcome. Finally, 79.4% of the students responded with "often" or "very often" to the question about learning effectively on their own, which suggests they gained confidence about continuing on their engineering educational pathway. These results support recent research that contends that active learning in a blended classroom can contribute to the development of cognitive skills such as critical thinking and problem solving (Yildiz et al., 2014; Cash, 2017).

In the institute-administered Course-Instructor-Opinion-Survey, student comments in the larger class (spring 2015) were equally, if not more, complimentary of the blended classroom format compared to the smaller class (fall 2013). Several students made extremely positive comments regarding the format, while expressing initial skepticism. For instance, one student wrote, "I loved the flipped classroom style of teaching. I was a little skeptical at first, but it ended up really working out." Another student commented on how the format allowed for a deeper understanding of the material: "[The] flipped classroom was really useful for getting a lot of practice doing problems. We used class time as more of an interactive assignment time which was much more helpful than just spending class time for lectures." This theme was echoed several times: "I love the reverse classroom system implemented in this class. Having lectures available for whenever I need to review anything and then having the TAs and the professor there to help was amazing. My favorite teaching format of any class I've ever had." Given that students continued to respond positively as the class size increased, their positive response in the surveys is another indicator of success with the format in terms of engagement.

The anonymous handwritten surveys revealed similar comments, but the responses to the question "Would you recommend this course format to a friend?" were more negative in the larger class. In the smaller fall 2013 class, the student responses to this question were: 27 "yes," 1 "no," and 5 "maybe." In the larger spring 2015 class, the student responses were: 40 "yes," 11 "no," and 4 "maybe." While both sets of responses were predominantly positive, the larger class had more "no" responses. Among the "maybe" responses, one student wrote, "Generally, I dislike flipped classes, but this one is structured well. It is not my preference, but I wouldn't turn people away from the class." This comment and the ones above suggest that the blended pedagogy needs to be well organized in order to encourage students to commit to the format. The survey responses for those students responding "no" indicate that they prefer to "be taught" the material and that they prefer to be able to "ask questions during lecture." While it may be their preference, "being taught" the subject matter is not the most effective means of learning, as reported in the literature on active learning and based on the instructor's observations. A few of the negative responses complained that the class format forced them to be engaged—which suggests a lack of self-awareness about how engagement helps them learn. The latter reason is not supported by the students' actual behavior. Both in previous traditional lectures and in the introductory period of the blended classroom sessions, few students have tended to ask questions. In fact, the data in figure 9.5 indicates that the number of students asking questions diminishes with class size, whereas engagement and performance are maintained as described above.

Table 9.5 shows mean values of the students' responses from the Course-Instructor-Opinion-Survey. The first five queries relate to the effectiveness of the instruction, which is influenced by the students' perceptions of the course format and the instructor. The results of the all-encompassing query "Considering everything, the instructor was an effective teacher" are 4.6 and 4.7 for the two classes, indicating a similar level of overall student satisfaction with the instruction despite the class-size difference. Independent-samples *t*-tests of the mean differences indicate no statistically significant differences between responses of the two groups of students on these five questions. The second five queries shown in table 9.5 relate most directly to the course itself. The mean values of the responses are again similar between classes, with four of the five results showing no statistically significant differences. The mean responses to one question, "Rate how prepared you were to take this subject," were statistically different (3.5 for fall 2013 and 4.0 for spring 2015). This is consistent with the above finding that the majority of the fall 2013 students were second-year students, while the majority of spring 2015 students were third-year. Overall, these quantitative results support the positive anecdotal comments presented above.

Figure 9.7 shows student-reported data (from the Course-Instructor-Opinion-Survey) for the number of hours spent per week on the course. More students reported spending 3–6 hours per week in the smaller fall 2013 class than in the larger spring 2015 class. Correspondingly, more students reported spending 9–12 hours in the larger spring 2015 class. The greater amount of

Table 9.5
Summary of results for the Course-Instructor-Opinion-Survey. Mean scores are for a 1-to-5 scale, as defined for each question. * indicates a significant difference

	Fall 2013	Spring 2015	*t* (*p*-value)
Number of responses	22	50	
Instructor's clarity in discussing or presenting course material. 5: exceptional; 1: very poor	4.4	4.5	-0.837 (0.406)
Instructor's level of enthusiasm about teaching the course. 5: extremely enthusiastic; 1: detached	4.2	4.5	-1.580 (0.119)
Instructor's ability to stimulate my interest in the subject matter. 5: made me eager to learn more; 1: ruined my interest	3.7	4.0	-1.444 (0.153)
Helpfulness of feedback on assignments. 5: extremely helpful; 1: not helpful	4.2	4.5	-1.801 (0.076)
Considering everything, the instructor was an effective teacher. 5: strongly agree; 1: strongly disagree	4.7	4.6	0.503 (.616)
Rate how prepared you were to take this subject. 5: extremely well prepared; 1: completely unprepared	3.5	4.0	-2.123 (0.037)*
How much would you say you learned in this course? 5: an exceptional amount; 1: almost nothing	4.3	4.4	-0.787 (.434)
Degree to which activities and assignments facilitated learning. 5: exceptional; 1: very poor	4.3	4.2	-0.112 (0.911)
Degree to which exams, quizzes, homework (or other evaluated assignments) measured your knowledge and understanding. 5: exceptional; 1: very poor	4.2	4.3	-0.948 (0.346)
Considering everything, this was an effective course. 5: strongly agree; 1: strongly disagree	4.4	4.4	-0.729 (0.469)

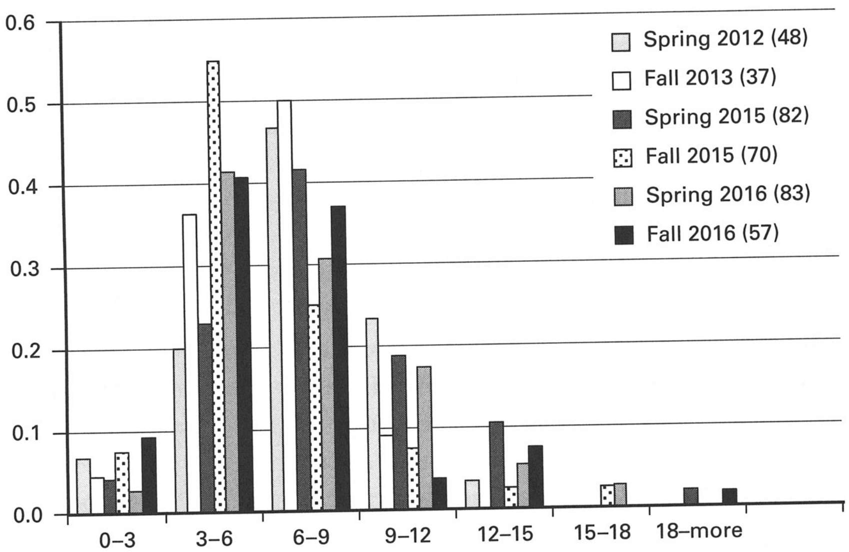

Figure 9.7
Student-reported hours per week spent on the course. Data are from the Course-Instructor-Opinion-Survey and are presented as the fraction of students in the class reporting for each range. The number of students in each class is shown in parentheses in the legend. Five classes were in the blended classroom format, and the spring 2012 class was in a traditional lecture-based format.

time spent on the course by these students may, in part, explain the higher average score on the final examination for the spring 2015 class (table 9.4). The spring 2015 distribution also shows approximately 10% of the students reported spending 12–15 hours per week. Comparison with data from three subsequent semesters of the course reveals that this is an atypical result with fewer responses in this range in other semesters (fall 2015, spring 2016, and fall 2016). Further, comparison to data from a previous traditional lecture-based class offered by the same instructor reveals a distribution that is very similar to the spring 2015 distribution, which suggests the blended classroom format is not overly demanding on student effort outside of the classroom sessions (consistent with conclusions in Webster et al., 2016). In fact, the percentage of

students reporting spending between 3 and 9 hours per week was always the majority and was consistently in the range of 65% to 86% across all classes reported.

DESCRIPTION OF INSTITUTIONAL SUPPORT

During development and delivery of the blended classroom pedagogy, the instructor received institutional support through several mechanisms. First, he received advice about implementing the blended pedagogy from the director of the Center of Teaching and Learning, the assistant dean (of the College of Engineering) for Educational Research and Innovation, and a small number of faculty colleagues (mostly notably in biomedical engineering and physics). Second, he received a small discretionary account from the College of Engineering to be used toward acquiring the needed technology, specifically the tablet PC and webcam used for the lecture recordings. Georgia Tech's Professional Education Division provided support for the lecture recordings by managing software and licenses, maintaining the servers, and responding to questions and problem reports. During the semester, the instructor used the institute's course management system to host the class website. The teaching assistants were supported by the School of Civil and Environmental Engineering through normal mechanisms provided to courses in the school. This typically consists of financial support for several hours per week of "grading" by an assistant, and the funds were used here instead to support the in-class assistants.

During the research phase of the project, the instructor received support from Georgia Tech's Center for 21st Century Universities, an organization that, among other tasks, assists faculty with research on alternative pedagogies. The researchers conducted a review of existing literature on this topic, administered the DCI and in-class surveys, and organized and analyzed data, which included statistical hypothesis testing. The institute also provided support by administering and managing the online Course-Instructor-Opinion-Survey.

CONCLUSIONS

The blended classroom approach described in this chapter for an undergraduate engineering Dynamics course required a substantial shift from a traditional teacher-centric approach to a student-centric format in which the instructor acts as a guide through the material and provides "just-in-time" tutoring. In addition to describing the pedagogy, the main purpose of this chapter has been to examine the effectiveness of scaling the approach to larger classes.

The conclusion is that the course format scales very effectively to larger classes based on the instructor's perceptions, assessment of student performance, assessment of student engagement, and review of student feedback. Students in the larger class showed similar gains on the DCI and they produced a higher mean score on a common final examination. Further, student-reported opinions of the class and its effectiveness were similarly positive in the larger class and in many cases exceeded the perceptions in the smaller class. In particular, students reported a similar level of engagement, despite the substantial difference in class size.

Moving forward as departments and institutes struggle with the value proposition in delivering engineering education, blended classroom approaches such as the one described here may provide a means of delivering a high-quality educational experience to larger classes. In fact, the motivation to offer the larger class was driven by department budget constraints, making it desirable to combine two moderate-sized classes offered in parallel during a given semester into a single larger class. While the generally accepted opinion is that larger class size leads to poorer student engagement, satisfaction, and performance, the results of this study suggest that the individualized benefits of the blended classroom approach scale to a larger class with little to no loss in effectiveness. It is important to reiterate that the course described here is not an online course. Rather, the course accurately fits the "blended" description in the taxonomy presented by Margulieux et al. (2016) by balancing delivery via instructor with delivery via technology and balancing information transmission with praxis. In the course design, the main objective was to use online and electronic technologies to enhance the in-class experience and effectiveness. Whereas

technology drives the out-of-class aspects of the course, the in-class experience is characterized by personalized tutoring interactions between students and instructors that lack advanced technology. In the instructor's observations and in student feedback, it is clear that student engagement and the in-class active learning are key to the success of the instructional approach. Hence, as instructors consider adopting similar approaches, it is recommended that besides taking technology considerations into account, they focus on designing the in-class activities and engagement aspects.

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