APPLYING BLENDED LEARNING TECHNIQUES:
Perspectives from Chemical Engineering Computation

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At the university level, the primary teaching method has been lecturing for hundreds of years.[1] In traditional lecture-based classes students passively receive the information from the instructor, while students participate in the construction of their knowledge when active learning strategies are employed in the classroom.[2] Traditional lecture-based classes are common in undergraduate engineering programs. Through several large studies that compared traditional lecturing with active learning methods, it has become clear that active learning methods improve students' performance and their ability to succeed.[3-6] The benefits from employing active learning methods have also been demonstrated for all sizes of classrooms and STEM disciplines.[2,3,6-9] In chemical engineering, faculty are aware of most active learning strategies, although the implementation of these methods is much less common.[10,11] Concerns about the time required in the classroom and during instructor preparation, norms in the field, expectations of the students, and physical limitations related to classroom layout and number of students have limited the adoption of active learning strategies.[12] Active learning includes a number of methods that require students to cognitively engage with the material being taught during class.[7, 13-14] While the number of strategies and their titles can be overwhelming, these methods all build on two fundamental principles. First, higher level cognitive learning enables students to construct problem-solving expertise.[10-15] Second, students' critical thinking skills and deep conceptual knowledge improve when they work with their peers.[16-17] It has been shown that students participate in actively constructing their knowledge through the dialogue process, even when no one in the group has a complete understanding of the concept.[18] In classic lecture-based classes these two important principles are usually only addressed outside the classroom through homework and casual groups of students working on their assignments together.[19] Furthermore, traditional homework assignments often only assess students' ability to use their knowledge in a limited set of applications that do not exercise in-depth analysis, relationship learning or evaluation. The traditional lecture model of teaching also limits feedback from the expert, the instructor, to at most comments on the graded homework and tests, impairing students' ability to create a deep conceptual understanding. Active learning methods that make class time available for activities that utilize higher level cognition and peer interaction while the instructor is available to provide immediate and targeted feedback helps students build expert thinking that they can rely on through their careers.[15]

Engineering has lagged behind other science fields when

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it comes to implementing evidence-based teaching methods.[10] For instance, there is a small number of published studies that address the use of online materials in flipped or blended classes for engineering disciplines.[20-21] In a flipped classroom, lectures that are traditionally delivered during class are watched by the students online before the class begins,[22] while blended classes are a mix of online and face-to-face learning.[23] Providing students with short video lectures has multiple benefits. Students can watch the material online at their own pace and re-watch as often as needed.[21] Instructors are alerted to weaknesses in students' understanding and flawed mental models when the students are required to answer conceptual questions covering the video lecture as an online quiz before attending class.[24] More class time is now available for students to analyze complex conceptual problems in peer groups with the feedback from their instructor.[15,25] There are even fewer studies that reported blended, flipped, and semi-flipped approaches in a numerical methods/computation class in engineering.[26-29] At the University of South Florida blended, flipped, and semi-flipped approaches in a numerical methods class for junior and senior mechanical engineers were compared.[26] The results were statistically equivalent, but the blended approach rated highest when students were asked about their perception of the learning environment; specifically, whether the students knew and helped each other, if the class activities were novel, the level of class participation, individualized interaction with the instructor, personal enjoyment of the class, and organization of the class activities.[26] At Utah State University, in a flipped numerical methods class for sophomore biological, environmental, civil, computer, and electrical engineers, the following three (out of eighteen) questions rated higher for the flipped class versus the traditional class: acquiring skills in working with others as a member of a team, developing creative capacities, and developing skill in expressing orally or in writing.[27] An entry-level applied computing class for Chemical and Materials Engineering students at the University of Barcelona used the flipped method.[28] Although the students found the flipped method too demanding, they felt positive about the self-learning, time management, effectiveness of time in class, and opportunities for feedback. Overall, while experience in implementing active learning methods in engineering classes is not abundant, these strategies are well-suited to building the critical thinking skills needed by engineers in the field.[10]

A blended classroom using online videos, conceptual questions and peer instruction[30] was employed in the Chemical Engineering Computation class at the University of Nebraska-Lincoln. Exact solutions for many engineering problems are infeasible and sometimes impossible to determine. The Chemical Engineering Computation class teaches different numerical methods for finding accurate approximations of these infeasible and/or impossible solutions, as well as the analysis of the results for stability and whether the results are appropriate for the situation. Teaching the complex concepts that are the basis of numerical methods can be improved through the use of active teaching methods in a blended class. In a traditional class setting, the complexity of the concepts covered can contribute to students coming to class without a basic understanding of the material. A significant amount of the class period is then spent developing the groundwork, therefore reducing the time available for feedback-driven, in-depth analysis of the material. The use of a blended classroom guides students in their preparation for class through short videos and conceptual questions while allowing class time for in-depth, expert-guided construction of knowledge through peer instruction activities. The development of the active learning strategies employed in the Chemical Engineering Computation class and the results of a survey that was used to explore the students' perceptions of these methods are reported and discussed in this work. Due to the small size of the class, the focus of this work is to showcase two points: the process used to apply blended learning in a chemical engineering course with numerical methods content and qualitatively describing the student engagement through a case study. In future studies, should the sample size be appropriate, the logical next step would be to conduct a within-group ANOVA comparison of student performance.

COURSE DESIGN

Course overview.

CHME 312, Chemical Engineering Computation, was designed to teach students how to apply numerical methods to solve realistic problems in the field of chemical engineering. Basically, students develop the skills necessary for formulating and subsequently solving practical problems using a numerical computing tool, MATLAB (Mathworks, Inc.).

A set of numerical methods for solving linear and nonlinear systems of equations, ordinary differential equations (ODEs) (i.e., initial value problems, boundary value problems, and linear/nonlinear stability analysis), partial differential equations (PDEs), linear programming/optimization, and the application of optimization to data regression and model identification are primary tools used by chemical engineers to solve diffusion, reaction, fluid flow, and mass and heat transfer problems.[31] In addition, statistical analysis including hypothesis testing, confidence interval, and regression/correlation is necessary to learn for any application. MATLAB, one of the most popular and widely-used mathematical packages, is the logical choice for all these numerical computing applications due to its unique capability of being a high-level programming language and a programming platform (with lots of built-in functions and modules). Thus, basic skills for anyone involved in chemical or related industries are the ability to formulate, solve, and analyze problems such as separations, reactor design, transport operations and control with the help of numerical computing. The desired outcome for the students taking CHME 312 is to master these skills to prepare them for almost all of the other chemical engineering courses they will take in the program.

CHME 312 is a mandatory course for all juniors in the chemical engineering program at the University of Nebraska and is offered both in the fall and in the spring semester. In addition, this course is a pre-requisite for two senior-level classes, namely Chemical Process Engineering (CHME 454) and Advanced Topics in Chemical Engineering Computation (CHME 496). Historically, the class size varies between 15 to 35, which is generally half of the entire body of juniors and transfer students.

Pre-Blended Course Structure

The pre-blended course was designed to incorporate in-class discussions with traditional lecturing. The course was held in three 50 minutes sessions per week for a total of 15 weeks. The instructor taught this course in the Spring 2017 semester and utilized much of the class time for traditional whiteboard and PowerPoint-based lectures, followed by peer instruction exercises (especially during the latter part of the semester) to drive meaningful discussion. The students were required to cover some of the basic material by themselves, although they very rarely did so and were, therefore, ill prepared for any meaningful discussion in class. This was also evident in their performance during the peer instruction exercises that addressed problem solving and/or common misconceptions. Hence, the instructor spent most of the class reviewing the basic material that the students were required to cover before class. In addition, no video lectures were posted online, and the learning management system Canvas was used merely as a communication tool, a place to record grades, and a repository for documents including lecture notes, homework assignments, and their solutions.

Instructional Challenges

In a broader sense, the pre-blended course structure posed two major types of instructional and learning challenges: (i) a lack of student engagement and (ii) difficulty in applying active learning and team approaches to teaching. In the pre-blended class, the instructor sought to create interactive, student-led dialogue as part of peer instruction exercises. These discussions were meant to serve as a tool for prompt feedback that pinpointed topics or content areas where students might be struggling while developing an exchange of ideas and cooperation among the students. Although it was essential for the students to study the materials assigned (before attending the classes) in order to engage in meaningful discussions with their peers and the instructor, they did so only a very few times. This often led to less organized and shallow discussions in the class. Throughout the semester students' ill preparation became a common theme despite the instructor's efforts to engage the students in active learning. Therefore, the instructor had to spend more class time on traditional lecturing and less time on the active learning activities in the classroom.

Post-Blended Course Structure

To address these challenges, the instructor redesigned the course following a blended approach to teaching and learning. Attending the ASEE Summer School for Chemical Engineering Faculty (2017) was instrumental in learning different active learning techniques, backward course design,[32] and their associated challenges and appropriateness for specific chemical engineering courses. In addition, over the course of the Fall 2017 semester, the instructor met with Dr. Tareq Daher, Director of the Center for Engineering Education Excellence in the College of Engineering at the University of Nebraska–Lincoln a few times to develop the course following this new design and to also pick the right software/tool for capturing lectures (see Figure 1 for details).

Using the backward design approach, the course was restructured as a blended course, with careful combination of online asynchronous and face-to-face active learning experiences. Using backward course design,[33] the course was aligned by centralizing modules in one folder for each of the three major topic areas covered in the class. Canvas was used to host content (i.e., slides, lecture notes, and video lectures), carry out surveys (on review sessions) and on-line quizzes (after watching the video lectures), and allow homework submissions. The navigation of the course was divided into six main areas: syllabus, announcements, modules, assignments, quizzes, and discussions. The modules section contained a 'module 0', among others, explaining the structure of the course, how to get started with Canvas, technical resources, and a participation form related to any activities (i.e., observation by peers and video recording of lectures). In addition, it included folders such as introduction to MATLAB, short video lectures, and lectures organized across three broader topic areas. Each of the lecture modules con-

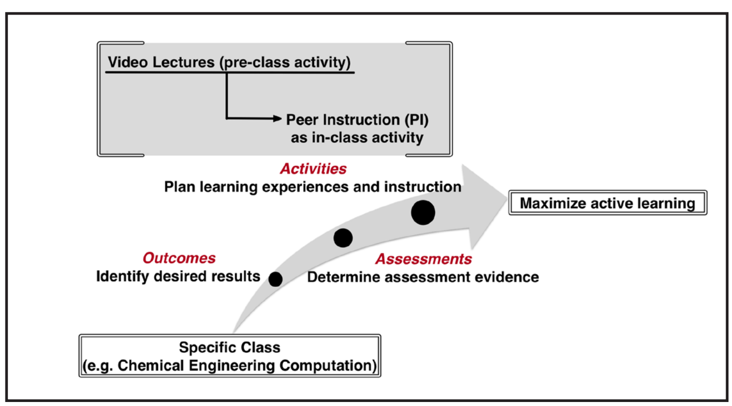

Figure 1. *Backward design of the blended class in order to maximize active learning.*

tained information on the online and in-class activities detailing the assignments, learning goals, and video lectures.

Following the blended approach, students were often asked to watch short video lectures before attending class and then answer the reflection questions based on the content. These questions were designed to gauge their basic understanding and to also probe common misconceptions. Thus, the questions served as a measure to prompt and encourage the students to pay more attention while watching the video lectures and subsequently complete the assigned work before meeting in the face-to-face class. Based on the students' responses to the reflection questions, concepts and misconceptions were further explained in the class by the instructor or students were asked to participate in peer instruction exercises to address these problems. Figure 2 shows a typical example on how to find whether a system of ODEs is numerically stiff to solve. When peer instruction exercises were employed, they were first asked to answer multiple-choice questions on their own. Then they were divided into groups, asked to discuss their answers with their peers, and come up with consensus answers for their group. Early in the semester the students sometimes struggled to recognize the connection between the online and in-class activities. However, they became more comfortable and saw the connections easier as these blended activities were used more often. Figure 3 represents one such activity on the 'tightening' or 'relaxing' of constraints and its effect on the 'basis' of the linear programming optimal solution. Although the increase in student engagement was evident based on in-class observations, a voluntary survey was designed and administered to gather data as explained in the following section.

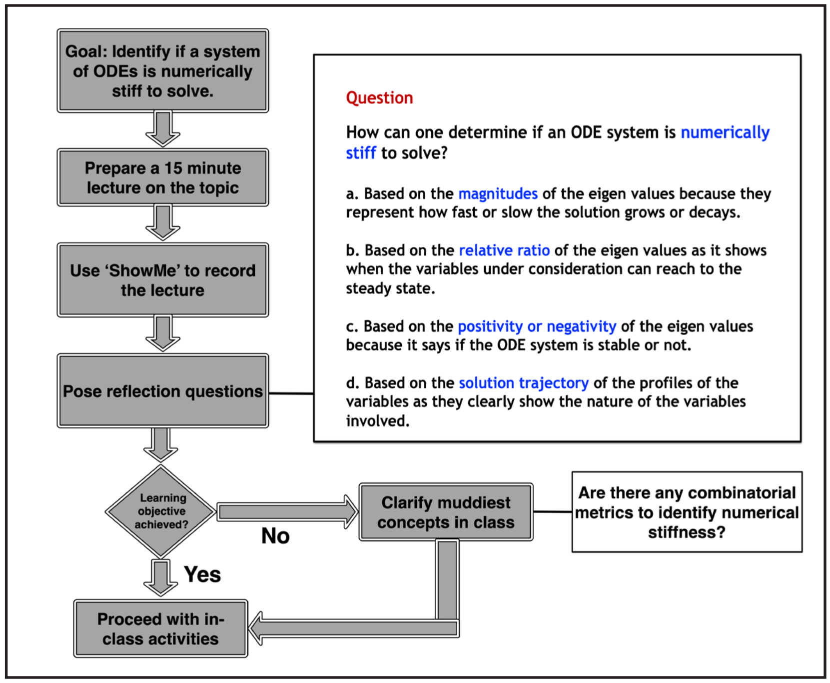

Figure 2. Steps for designing pre-class activities. Here, stiffness of an ODE system is used as a case study.

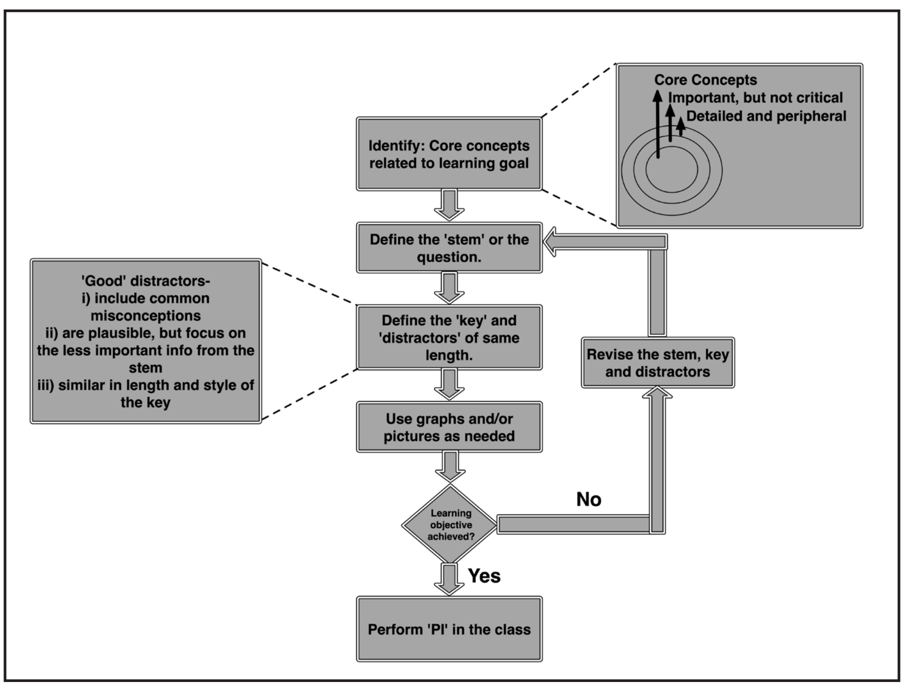

Figure 3. Steps for designing a peer instruction (PI) exercise using stem, key, and distractor. Here, the tightening or relaxing of constraints along with its effect on the basis of a linear programming optimal solution is used as a case study.

METHODS

The purpose of this research was to explore how undergraduate chemical engineering students' perceptions are impacted by blended course design and active learning while taking a chemical engineering computation course. This research followed a qualitative case study research design. The phenomenon in this study was the change in undergraduate chemical engineering students' perceptions and engagement in the context of the computation course. The boundaries between the phenomenon and its context are not clearly evident; therefore, a case study design is appropriate for this study.[34] The case in this study is the engagement with content and learning of undergraduate students. The unit of analysis was bounded in the context of a numerical methods course. The research questions and purpose of the study required an explanatory case study design, as recommended by Robert Yin,[34] to explain the intervention of active learning activities within the context of a blended course.

Lecture Capture

ShowMe (Learnbat, Inc.) was used to record lectures. ShowMe helps turn an iPad into an interactive whiteboard and allows the recording and online sharing of voice-over whiteboard lectures. The instructor delivers the lecture similar to a traditional classroom but uses an iPad instead of a whiteboard. The length of the lecture was intentionally limited to no more than 15 minutes since shorter video lectures (of 15 minutes or less) are reported to be more effective for student learning.[35] Each lecture covered the breadth of the concept being taught, including basic theorems, common misconceptions, and muddiest point (as gathered in the class from the students). For teaching CHME 312, the instructor developed 30 such short video lectures.

Assessment Tools

In order to evaluate this blended class, the instructor applied three different assessment techniques, including formative assessment, summative assessment, and student survey.[36-37]

Formative assessments of student learning not only help students identify their strengths and weaknesses on the subject matter, but also allow the instructor to customize their teaching.[38] In this blended class, muddiest point, one-sentence summary, and documented problem solutions were employed as formative assessment techniques. Muddiest point asks students to write down the most confusing concept of a particular lesson or topic. Through this process, the students can engage in metacognition and reflect on their own understanding on a deeper level. One-sentence summary is another formative assessment technique in which students write one sentence to summarize the topic. Basically, it allows the instructor to assess the synthesis and creative thinking abilities of the students. For this class, the students were asked to either answer a muddiest point question or write a one-sentence summary after each of the in-class activities and also after watching each of the short video lectures. Documented problem solutions assess the ability of the students to solve problems. In this class, the students were asked to solve the problems and also report their approach for getting the solutions by detailing the solution steps. Hence, this technique mainly focuses on metacognitive skills and the students, as a result, gain more understanding of the problem-solving process.

Formative assessments for this blended course also included quizzes after watching the video lectures and benchmark problems in the midterm and final exams. A quiz containing 3-5 multiple-choice or short essay questions was used to evaluate students' understanding of concepts covered in the video lectures. To assess students' involvement and perception of this blended class, a survey was conducted. It included 12 questions (9 multiple-choice and 3 short- essay) covering their engagement with the video lectures and in-class activities, their level of participation in class and at home, and also their opinion on what should be changed or improved.

Implementation

Creating the blended learning environment via implementation of active learning techniques and recording short video lectures can be categorized into three different phases: phase 1 (pre-class activities), phase 2 (in-class activities), and phase 3 (post-class activities).

The short video lectures were uploaded on Canvas at least two days before the in-class sessions. The pre-class activities included watching these lectures and then completing the pre-class assignments; either answering multiple-choice or short-essay questions, writing one-sentence summaries, and discussing the muddiest point. These pre-class assignments were due at least 12 hours before the in-class session, which provided enough time for the instructor to determine the level of the students' understanding and customize the content and organization of the face-to-face sessions (see Figure 2 for the steps involved in designing one such activity on a specific topic). For example, after completing the pre-class activities covering stiffness of an ODE system (Figure 2), the students' answers to the muddiest point question made it very clear that the majority of them were confused about the existence of any combinatorial metrics. This confusion was used as the basis for an in-class discussion.

The in-class activities usually had three major elements. First, the muddiest points, as reported by the students after watching the video lectures, were discussed and further clarified by the instructor by citing more examples (when needed). Second, either some new concepts were introduced and explained by the instructor or multiple-choice questions (related to common misconceptions or solutions of chemical engineering problems) were posed, followed by student participation in peer instruction (PI) exercises (see Figure 3 for the PI case study using the tightening or relaxing of constraints along with their effect on the basis of a linear programming optimal solution). During the peer instruction exercises, the linear programming problem was defined, the stem was formed, and the key as well as the distractors were defined. A relevant graphic was provided to clearly represent the problem. The students first had 2-5 minutes to read, work on the question, and provide individual answers. After that, groups of two or three students discussed their solutions, developed consensus answers for the group, and also wrote down the steps for solving the question for 5-10 minutes. Third, the students were asked to either a write one-sentence summary or discuss the muddiest point based on the topic/content covered in the same class, which sometimes led to the instructor developing a video lecture for further clarification.

As part of the post-class activities, homework assignments were assigned to the students on a major content/concept basis to probe their overall learning experience. In addition, benchmark calculation problems were included in the midterm and final exams. Students were also asked to complete a survey, as a voluntary exercise, on their perception of the blended learning experiences.

RESULTS

A post-assessment survey was administered after students participated in the blended learning exercises in order to collect students' perceptions. Eight out of the 12 students (67% response rate) responded to the survey. The survey questions are categorized into three broad categories: student effort, students' perceptions of blended learning, and students' comments on class components that they liked or things that needed to be improved.

Student Effort

Of the students that participated in the post-assessment survey, 50% said they agreed or strongly agreed with the statement that they watched the videos on time (before class), and 25% of the participating students neither agreed nor disagreed, which could indicate they watched some of the videos before class but not others. The rest of the students, 25%, said they somewhat disagreed with the statement that they watched the videos on time. When watching the videos, 13.6% of the students reported that they took notes and 9.1% said that they marked in their notes when they had questions. 36.4% of the participating students reported that they re-watched sections of the video when they did not understand a concept, and 27.3% stopped the video as needed to accommodate their schedule, write down thoughts, etc. Distractions were a problem for the students watching the videos at home. No student said that they watched the videos with 100% of their attention, and 13.6% reported being distracted often by social media, their phones, etc.

The results for watching the videos on time are similar to the students' self-reporting of the effort they spent at home preparing for the class. A total of 50% agreed that they had spent more than enough effort at home preparing for the class, while 12.5% were undecided and 37.5% disagreed with the statement. These results are in contrast to the effort the students said they expended in the classroom. All the students said they strongly agreed or agreed with the statement that they spent more than enough effort in class working on understanding the concept(s) being taught. After watching the videos, 75% of the students reported that they felt confident in their understanding of the material before class while 25% neither agreed nor disagreed with the statement that they felt confident in their understanding after watching the pre-class videos.

Students' Perception

The students generally had a positive perception of their learning experience in the blended classroom. A total of 75% of the students participating reported that they agreed or strongly agreed with the statement that peer instruction, working with their peers during class to solve problems, improved their learning experience while the remaining 25% neither agreed nor disagreed with the statement. The blending of online videos watched at home with peer instruction and classroom instruction created an active learning environment where 87.5% of the students said that they felt engaged. The remaining 12.5% disagreed with the statement that watching the videos as homework and working in class with their peers to solve problems created an active learning environment where they felt engaged. 75% of the students participating thought that the blended classroom environment was more engaging than traditional lecture classes while 12.5% neither agreed nor disagreed and 12.5% disagreed.

The majority of the participating students felt like the blended classroom made them more responsible for their own learning, 57.1% agreed with the statement, 28.6% neither agreed nor disagreed, and 14.3% disagreed. 75% of the students strongly agreed or agreed with the pre-class videos and reflection questions preparing them for the face-to-face activities in the classroom. 12.5% of the students neither agreed nor disagreed with the pre-class videos and reflection questions preparing them for class and 12.5% of the students disagreed with the statement.

Students' Comments

The students were asked to comment on what they liked about the blended classroom and what components were the most helpful. Understanding the material before the start of class gave them confidence to actively engage in class, which made class more interesting. Other students commented on using the videos and reflection questions to clear up misconceptions and that the ability to re-watch the videos helped them gain a clear understanding of the material. One student commented that peer instruction helped them explain the concept in "layman's terms", which could be an indication of strong conceptual knowledge.

The students were also asked what they would like to see changed in the blended classroom. Most of the comments were related to implementation, such as timing and availability of videos. One student said it would be better if they could see the professor in the videos, not just what is being written. This student said it was easier to focus on the video when the professor was visible. The students also asked for more concepts to be covered in video lectures and that more examples are included.

DISCUSSION

The blended learning approach is a new concept in engineering, especially in chemical engineering computation or numerical methods classes.[26-29] One of the critical factors in designing a blended class to teach this topic is creating and balancing pre-class, in-class, and post-class activities with enough graphics and equations to explain the application of numerical methods in chemical engineering problems such that these are not overwhelming but engaging to the students. Based on the experience gathered from the pre-blended class, one of the biggest challenges was the lack of student engagement that was rooted in their poor pre-class preparation. To this end, the blended learning approach not only addressed several of the course's instructional challenges (including student engagement) but also appeared to engage and benefit the students. Although the students had little or no previous experience in a blended classroom, they actively participated in the process. They actively engaged in the class via peer instruction activities instead of just passively listening to the lectures, as in a traditional classroom setting. As reported by the students, the peer instruction activities improved their learning experience. When comparing the success of the peer instruction activities between the class taught by the same instructor in 2017 and the class using blended learning, sufficient student preparation, facilitated by the online videos and assessments, appears to be the difference.

Guided by the recommendations from literature on blended learning, the sequence of learning activities was designed as follows: students watch pre-class video lectures (on new concepts or clarification of muddiest points reported in class) ➔ students participate in on-line quizzes, summarize the content, and discuss muddiest points ➔ the instructor addresses the online-reported muddiest points during class ➔ the class discusses new concepts, problems, or common misconceptions in class ➔ the class participates in peer instruction ➔ students summarize the content and discuss muddiest point. The improvement in students' pre-class effort can be attributed to the structure provided by the video lectures and on-line quizzes (as shown in Figure 2). With the fundamental knowledge gained or some misconceptions cleared, the students typically were engaged in more critical thinking and deeper discussions when participating in peer instruction exercises (as represented in Figure 3).

In addition to judging their own effort and reporting their perceptions of the blended learning, students also commented on things that needed to be changed or improved. Two such key recommendations included making video lectures with the instructor visible (instead of just screen casts) and covering more example problems in the video lectures. Overall, based on the experience gathered during this class, the blended approach could potentially facilitate a better learning experience for students in chemical engineering by engaging the students and facilitating higher-order cognition through peer instruction. The teaching involved would also be highly efficient for instructors once the sequence of innovative activities is in place.

CONCLUSION AND FUTURE DIRECTIONS

The students from the Chemical Engineering Computation class widely accepted the blended approach and believed that it enhanced their learning. They also felt more engaged in the learning activities as compared to a traditional class. This was the first time the instructor implemented all of these active learning techniques in this class. Hence, further data gathering and analysis are needed to reach to a concrete conclusion about their effectiveness. One of the major limitations of this study is that the data gathered was qualitative, mostly representing student perceptions, and further statistical analysis such as ANOVA could not be performed due to smaller sample size. Therefore, the performance of the students should be included as quantitative measures in future semesters. Given the low percentage of students that reported taking notes while watching the videos, the researchers intend to incorporate study strategies that can guide students on how to take quality notes.[39] In addition, in response to the students' feedback, the instructor will use a light-board to create videos (with the instructor visible), cover more example problems that are better aligned with the learning outcomes, and post the videos at least a few days earlier than the in-class meeting in the coming semesters. Overall, the blended classroom addressed the instructional challenges faced during the previous class and better supported the students' creation of expert knowledge. The methods used will continue to be employed in the Chemical Engineering Computation class with the improvements discussed in support of maximizing student outcomes.

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