FLIPPING THE CLASSROOM FOR A MATERIAL AND ENERGY BALANCES COURSE: EFFECT ON STUDENT LEARNING VERSUS STUDENT PERCEPTION AND SENTIMENT

Victor K. Lai
University of Minnesota • Duluth, MN 55812

INTRODUCTION

The flipped classroom has become an increasingly popular pedagogical approach to teaching since the mid-2000s. Broadly, a flipped classroom, as contrasted with a traditional classroom lecture environment, requires students to learn and understand the material prior to class (via prescribed textbook readings, pre-recorded videos, etc.); class time is dedicated to group discussions and/or students working on example problems collaboratively. Bishop and Verleger argue for a narrower definition as "an educational technique that consists of two parts: interactive group learning activities inside the classroom, and direct *computer-based* individual instruction outside the classroom."[1] From a student's perspective, this method of instruction requires frequent out-of-classroom engagement with the class content compared to traditional classroom instruction, where material engagement is typically limited to completion of weekly homework assignments and studying for exams. In many instances of flipped classes, however, homework assignments are drastically reduced in length, or even eliminated altogether, as the homework problems are now used for in-class group activities. This trade-off works as a useful "carrot" offered to the students, in that there is generally little difference in the total amount of time spent on the class material outside the classroom.

While many studies across a variety of disciplines have shown the effectiveness of a flipped classroom in improving student engagement and learning in science, technology, engineering, and mathematics (STEM) courses[2–4] as well as other fields,[5–8] student perception is disproportionately less positive in some cases. Negative perceptions include depersonalization from the instructor,[9,10] inability to ask questions immediately when learning the material from videos,[10–12] higher student workload and time commitment,[10,13] and a learning style that fits the traditional lecture format.[12,14] Anecdotally, I have had multiple student advisees deliberately avoid flipped classroom sections of their General Chemistry class, citing poor learning experiences from prior flipped classes. This paper presents the methodology, student survey results, and grade comparisons with prior semesters for implementing the flipped class format for the Material and Energy Balances (MEB) class, a sophomore-level foundational Chemical Engineering class, at the University of Minnesota – Duluth (UMD).

METHODOLOGY

Class Curriculum

Prior to Fall 2016, the Material and Energy Balances class was a three-credit sophomore level class with three 50-minute lectures per week. The class was subsequently increased to four credits with the addition of a 50-minute recitation session on Thursdays conducted by graduate teaching assistants in response to students' feedback for more in-class examples. Material covered in this class follows closely the textbook *Elementary Principles of Chemical Processes* by Felder, Rousseau, and Bullard (Wiley, 4th Edition). Student

Victor K. Lai *is an Assistant Professor in Chemical Engineering at the University of Minnesota – Duluth. He received his PhD from the University of Minnesota – Twin Cities in Materials Science and Engineering in 2008. His research focus is in the mechanics and transport phenomena of biological soft tissues.*

learning was assessed via weekly homework sets graded by teaching assistants, 10-minute quizzes (weekly, except during midterm weeks), 50-minute midterm exams (four exams total throughout the semester), and a comprehensive final exam. The breakdown of the content covered for each exam is as follows:

- *Midterm Exam 1*: Introduction to Engineering Calculations, Process Variables, and Balances on Non-Reactive Processes (Chapter 2, 3, 4.1 – 4.5)
- *Midterm Exam 2*: Balances on Reactive Processes (Chapter 4.6 – 4.9)
- *Midterm Exam 3*: Single Phase Systems (Chapter 5), Multi-Phase Systems (emphasis on vapor-liquid equilibrium only – Chapter 6.1 – 6.4)
- *Midterm Exam 4*: Energy Balances on Non-Reactive Processes (Chapter 7, 8.1 – 8.4)
- *Final Exam*: content from Midterm Exams 1 – 4, plus energy balances using psychrometric charts (Chapter 8.4)

It should be noted that, unlike some other classes where different exams evaluate largely different material separate from previous exams, the content in this class builds incrementally over the entire semester; subsequent exams require proficiency in knowledge of the content from previous exams.

Flipped Class Setup

This class was taught by the author using the traditional lecture format in Fall 2014, Spring 2015, Fall 2015, Spring 2016, and Spring 2018 (semesters not listed here indicate that the class was taught by a different instructor during those semesters). In Spring 2019 a hybrid of instructional methods was used, with traditional lectures for content up to midterm exam 2 and the flipped class method thereafter. For the flipped class portion, students were required to watch pre-recorded video lectures and/or accompanying worked examples (usually 1-2 examples per lecture) prior to class; students were assigned up to 30 minutes of videos per class. A total of 55 lecture videos and examples, ranging from 4 to 40 minutes in length (mean: 16 min; median: 13 min) were created during the summer months in 2018 as part of the development of an online version of this course. These videos were made with the assistance of the video production team at the Academic Technology Support Services (ATSS) located at the University of Minnesota – Twin Cities, who were able to create professional quality videos using state-of-the-art technology and resources. Lecture videos contained a talking head in addition to the slide contents (Figure 1A); some of the video examples utilized the Lightboard technology, where a large piece of glass illuminated with LED lights is used similar to a whiteboard (Figure 1B). It should be noted that the significant investment of time to create these videos is a one-time investment – once created, these videos will be used repeatedly over future semesters. To keep students accountable, partial notes were posted for each lecture video, and students were required to show completed notes at the start of each class. Similarly, for the worked example videos, students actively follow through the videos by copying solutions to these problems. These pre-class assignments constituted 50% of their homework grade for that week. The use of class time was generally broken down as follows:

- *First 10 minutes (or less)*: Recap of the video lecture slides and/or worked example by the instructor, emphasizing key concepts that tended to be unclear for students (based on experiences from prior semesters). It should be noted that the amount of time spent on the recap is only a fraction of the length of each video; the speed at which the recap occurs required students to already know what is going on (i.e. they have prepared by watching the videos) to be able to understand and follow the recap. This recap also allowed the instructor to field some questions from students to help clarify common misconceptions right away to the entire class.
- *Next 35 minutes*: Students worked on assigned problems that were previously part of the homework set for that week, either individually or in groups. During this period, I occasionally stopped the discussions immediately to address and clarify any common misconceptions or mistakes observed from multiple groups or individuals.
- *Last 5 minutes*: The solution to the in-class example was projected on the screen, and I went over the entire problem briefly. In some cases, students were required to complete the entire problem outside of class and show their completed work at the start of the next class period, together with their notes/examples from the videos. The full solutions were eventually posted to the class website for students' reference.

With this flipped class format, the length of the weekly homework sets was cut down by around 80% on average, with some homework sets eliminated completely for that week.

Data Collection and Statistical Analysis

Prior to switching to the flipped class (during the last week of the non-flipped portion), students were asked to complete a pre-survey to gauge their experience and sentiment towards flipped classrooms. At the start of the pre-survey form, students were provided the following definition of a flipped classroom:

"The flipped classroom model is described as 'a pedagogical model in which the typical lecture and homework elements

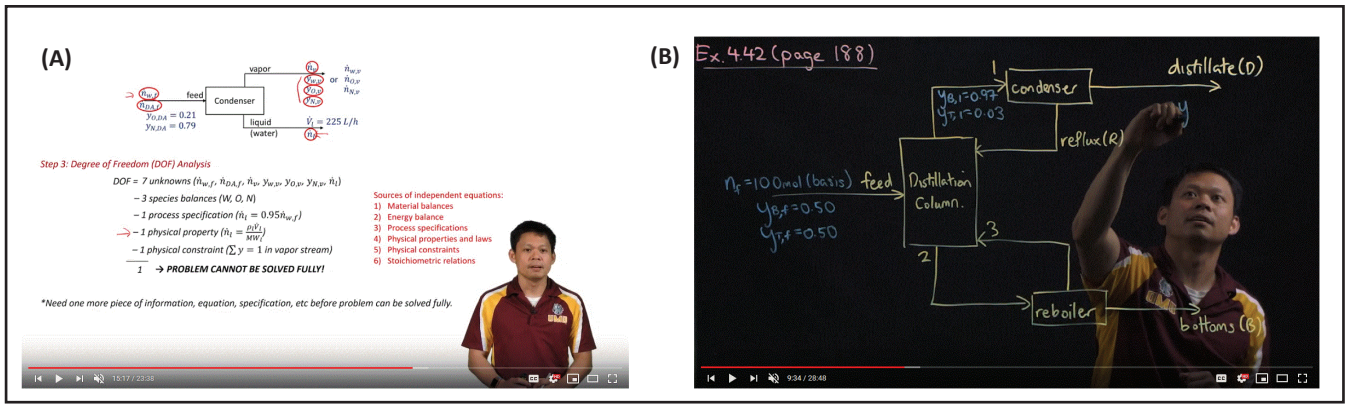

Figure 1. (A) *Video still examples of a video lecture and (B) video examples using the Lightboard technology. These videos were created in a professional studio setting at the University of Minnesota – Twin Cities campus, with the on-site assistance of video producers at the Academic Technology Support Services.*

of a course are reversed. Short video lectures are viewed by students at home before the class session, while in-class time is devoted to exercises, projects, or discussions'.

The intent of a flipped classroom model is 'to have the students engage the material before class so that the instructor can engage the students during class, taking the focus off the instructor and onto student learning.' "[14]

Students were asked two main questions in the pre-survey: (1) their preference for flipped classrooms compared to traditional lectures; and (2) how well they felt they learn in a flipped classroom compared to traditional lectures. Students who have never attended a flipped class before were asked to answer the same questions purely based on their perception of flipped classes, solely on the definition provided. At the end of the semester, just prior to the final exam, a post-survey with the same two questions was administered to track any changes in student sentiment towards a flipped classroom after this experience. In addition, students were asked if they would be willing to take another flipped class again. Analysis on differences in student sentiment before and after the flipped class was performed by assigning a numerical value using a 5-point Likert scale for each response, and an average value is reported for comparison.

To quantify the effect of instructional method on student learning, grades for the midterm exams and final exam from the semesters the instuctor previously taught the course were aggregated for comparison. Only the scores of students who completed the entire semester were included for comparison. Paired t-tests between exams were performed within each semester to identify differences in scores within the same cohort of students.

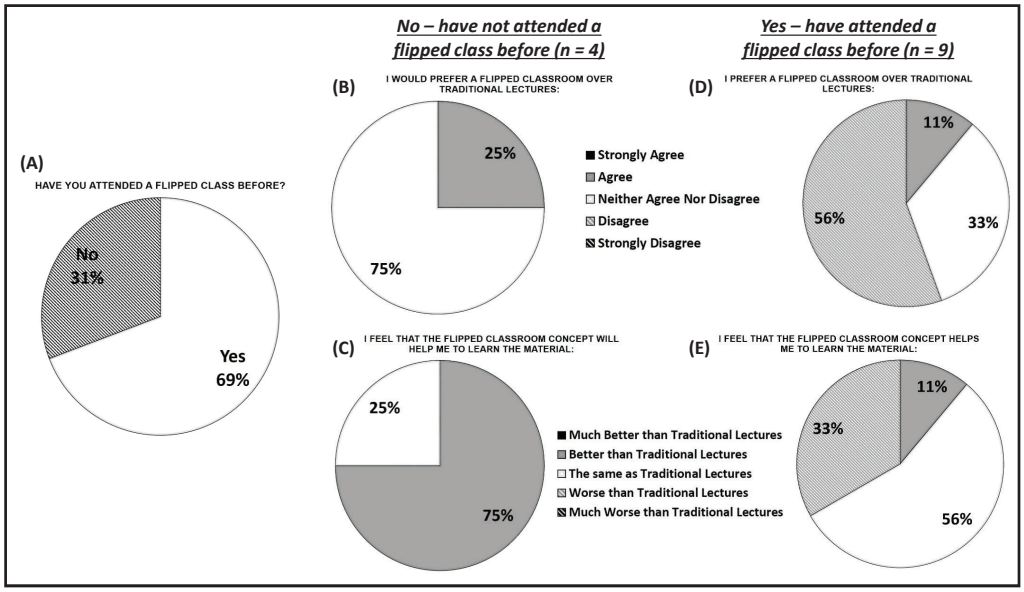

Figure 2. *Pre-survey results from students prior to the switch to a flipped class method of instruction (n = 13). More than half the students have had experience with a flipped class before. Students who have never attended a flipped class expressed more positive sentiment towards the idea of a flipped class (B and C), compared to students who have attended a flipped class before (D and E).*

RESULTS

Figure 2 shows the student responses from the pre-survey (n = 13). More than half of the students (n = 9) had attended a flipped class before – either in General Chemistry II (7 students), General Biology I (1 student), or high school physics/chemistry (2 students). In general, students who had never attended a flipped class (n = 4) expressed cautious optimism towards this approach; all indicated at least neutral or positive preference for a flipped class (Figure 2B), and 75% felt that they would learn the material better compared to traditional lectures (Figure 2C). These responses are in contrast to students who had taken a flipped class before: more than half (56%) preferred traditional lectures (Figure 2D), while only one student felt he/she learned the material better in a flipped classroom (Figure 2E). These students who had taken a flipped class before were also asked to provide optional comments regarding their preference, as shown in Table 1. These comments (positive comments bolded and italicized; negative comments underlined) are generally consistent with previously published surveys regarding student sentiment and feedback.[2-4,10-14] Students enjoyed that they could learn at their own pace, and the videos allowed them to replay segments when necessary. However, many students felt that they learned the material better in a traditional lecture format (learning style preference), expressed concern for an increased workload, and disliked not being able to ask questions for clarification right away during the videos.

Figure 3 shows the exam grade comparisons for each semester, with Table 2 summarizing scores across all semesters. While a total of ten paired t-tests comparing exam scores were performed for each semester, for clarity, only statistically significant differences with Exam 2 are shown in Figure 3 as denoted by an * ($p < 0.005$ with Bonferroni correction). Exam 2 was highlighted because this exam tended to be the highest scoring exam. It should be noted that the addition of a discussion section after Fall 2016 did not have any obvious effects on the exam score trends within each semester. Prior to Spring 2019, similar trends are observed as the semesters progress. Exam 1 scores tend to be low; as the first true Chemical Engineering class for the students (outside of an Introduction class), this class sets the tone for the program for students in terms of difficulty and workload, such that the majority of students need time to figure out and adjust to the rigor of the class (and program overall). Exam 2 generally sees a significant improvement (and usually the peak) in

TABLE 1
Written sentiments from students who have attended a flipped class before, grouped according to their responses as to whether they prefer a flipped class over traditional lectures (Figure 2D). Comments are copied verbatim from the survey. Positive comments are bolded and italicized; negative comments are underlined.

Agree	"It depends but what I like is that ***I can watch videos and pay attention to them on my own time as well as replay the video to understand what I didn't catch before.*** I don't like it when I can't ask any questions right at the moment that I watch the video."
Neither Agree Nor Disagree	"For chemistry I loved it and was able to learn very well with a flipped classroom, but with MEB I just worry that I will not have enough time in class to 'practice' the material learned prior to coming to class and won't be able to motivate myself to practice more problems outside of class to get a better understanding." "I like that ***I can learn at my own pace*** and then ask questions for clarification in class."
Disagree	"I don't feel like I learn the material as well that way. I find it hard to learn concepts and not be able to ask questions right away that confuse me." "Personally I find that my grades always are lower in flipped classes than they are in regular classes. I think it's because I feel like I have more homework than I would normally have in regular classes so I try to rush to get everything done rather than taking my time to understand the material." "I find it harder to learn the material" "I have found that I retain the information presented much more consistently when it is taught in a traditional format" "I feel I learn a lot better in a non-flipped course, and just in general prefer it to a flipped. I learn a lot better when hearing the material in person from a professor and going through that material with them rather than watching it online."

Table 2
Summary of average exam scores for all semesters; standard deviations shown in parentheses.

Semester	Class Size	Exam 1	Exam 2	Exam 3	Exam 4	Final Exam
Fall 2014	38	66.8 (17.0)	86.9 (11.4)	64.7 (23.1)	66.7 (17.7)	82.8 (12.7)
Spring 2015	29	62.2 (13.4)	82.6 (10.1)	68.4 (16.6)	77.2 (13.9)	62.7 (11.9)
Fall 2015	41	68.7 (17.6)	79.2 (16.7)	77.8 (16.1)	72.4 (17.3)	75.1 (17.7)
Spring 2016	35	77.5 (13.2)	87.0 (13.0)	66.1 (21.4)	73.2 (16.9)	75.1 (16.4)
Spring 2018	26	66.5 (14.6)	80.2 (15.0)	68.0 (17.6)	67.5 (16.6)	79.9 (18.8)
Spring 2019	17	67.9 (14.0)	76.6 (15.4)	76.0 (17.8)	78.1 (15.6)	79.9 (13.6)

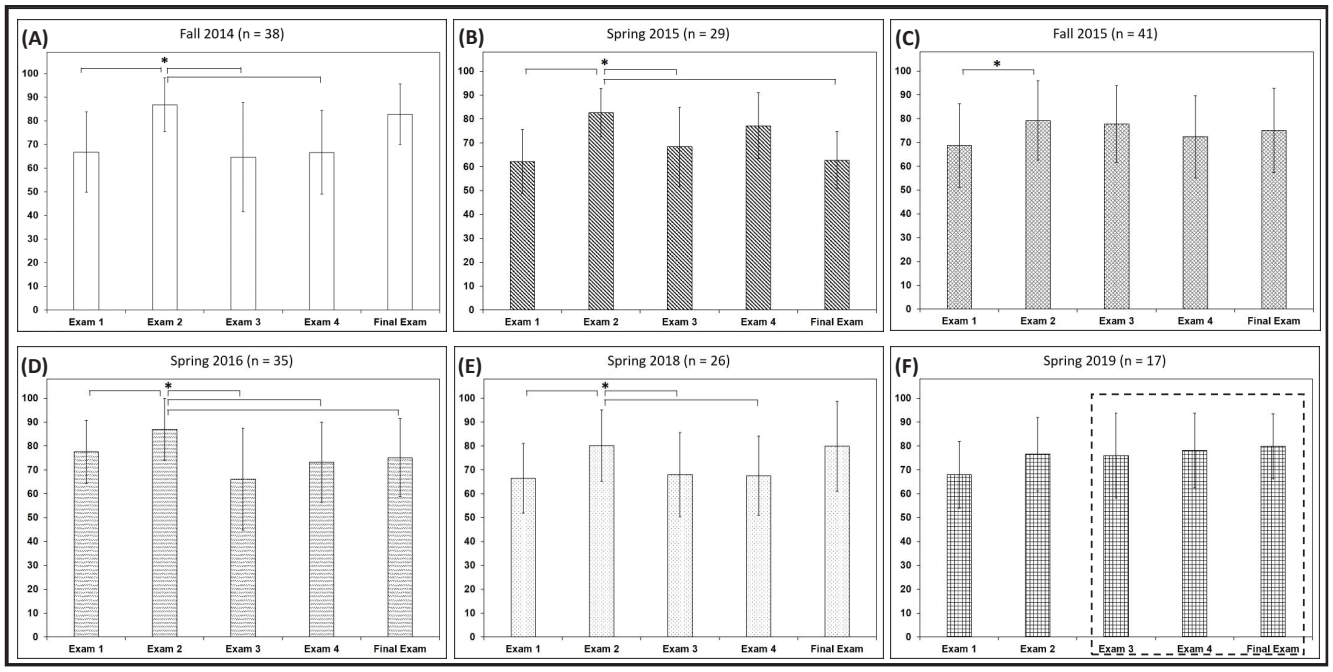

Figure 3. *Comparison of exam scores across 6 different semesters. Exams administered after the switch to a flipped class in Spring 2019 are indicated by the dotted box. Statistical significance at the 0.005 level (with the Bonferroni correction) between Exam 2 and the other exams are indicated by *. For clarity, all other statistically significant differences in exam scores are not shown.*

grades, as students become better adjusted and more familiar with the problem solving steps, and the incremental addition of chemical reactions to the problems is an easy review from General Chemistry for most students. As such, Exam 2 scores are often statistically higher than scores of other exams, as seen by the frequency of * in Figure 3. Exam 3, however, usually sees a drop in scores, as students wrestle with new concepts of non-ideal gases and vapor-liquid equilibrium incorporated into the material balance problems. Thereon, there are no observable trends for Exam 4 and the final exam, although scores for these exams typically never exceed those of Exam 2. Interestingly, the switch to a flipped class method (indicated by the dotted box in Figure 3) exhibited a slightly different trend: the grades from Exam 2 are not statistically different than scores of the later exams, which suggests that these peak scores are sustained into the semester across the later exams with the flipped classroom. This sustained exam score is only observed in one prior semester (Fall 2015).

Figure 4 shows the post-survey results after the students have completed the semester's coursework (but prior to the final exam). All students indicated neutral or positive preference to a flipped classroom (Figure 4A), and only one student felt that he/she did not learn the material as well compared to traditional lectures (Figure 4B). This overall positive sentiment towards the flipped classroom method is observed despite more students (21%; 3 out of 14) who felt that their grades did not improve after the switch (Figure 4C). While these survey results suggest an improved learning experience with the flipped class, students still appear hesitant and less enthusiastic about taking another flipped class (Figure 4D) – only 34% (5 out of 14 students) expressed that they would choose a flipped class over a traditional lecture class if given a choice, with 50% of the class (7 students) indicating neutral preference. Comparison of these survey results on a Likert scale in Figure 5 shows there is an improvement in student sentiment towards a flipped classroom, both in terms of preference and perception of learning, which suggests an overall positive experience with the flipped classroom. Taken together, these survey results are consistent with studies such as Deslauriers et al. that reported negative correlation between student sentiment towards active learning with actual test scores;[15] however, student attitudes can improve throughout the semester with instructor explanation and facilitation of active learning.[15-17]

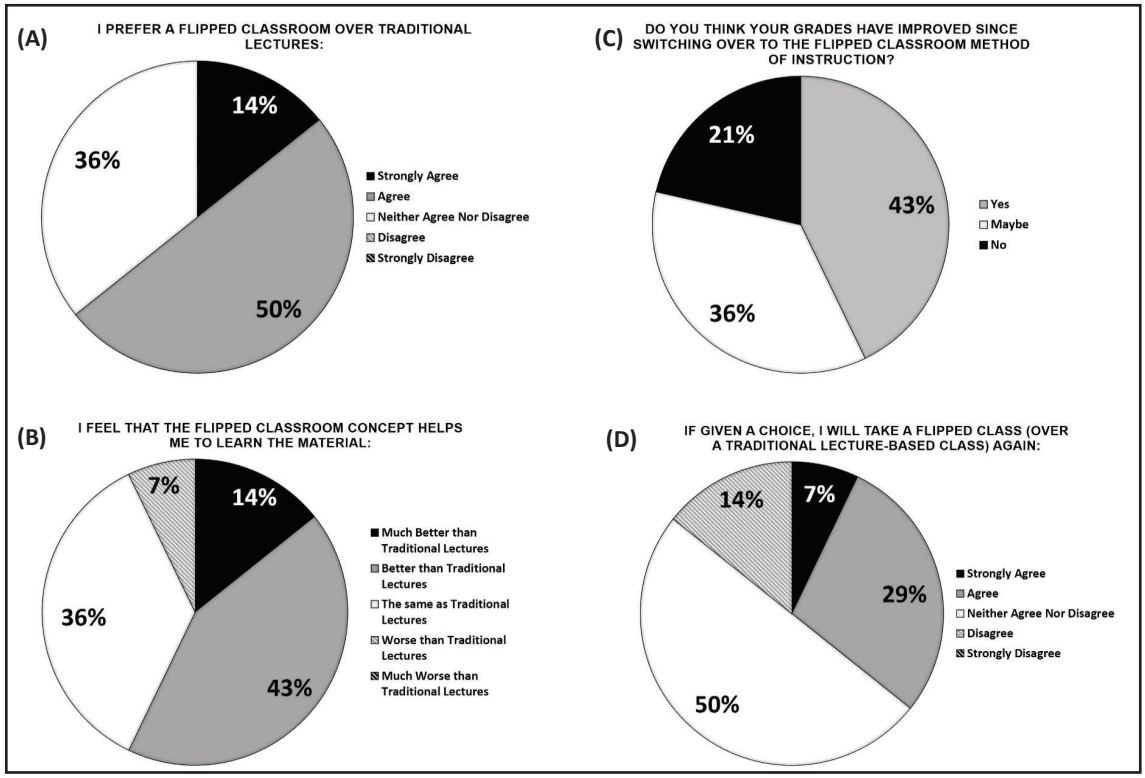

Figure 4. *Post-survey results from students administered just prior to the Final Exam (n = 14). Students expressed greater positive sentiment towards a flipped classroom (A and B) compared to pre-survey results, despite a significant proportion feeling that their grades were not improved (C). However, many students still appear hesitant to choose a flipped class over a traditional lecture class (D).*

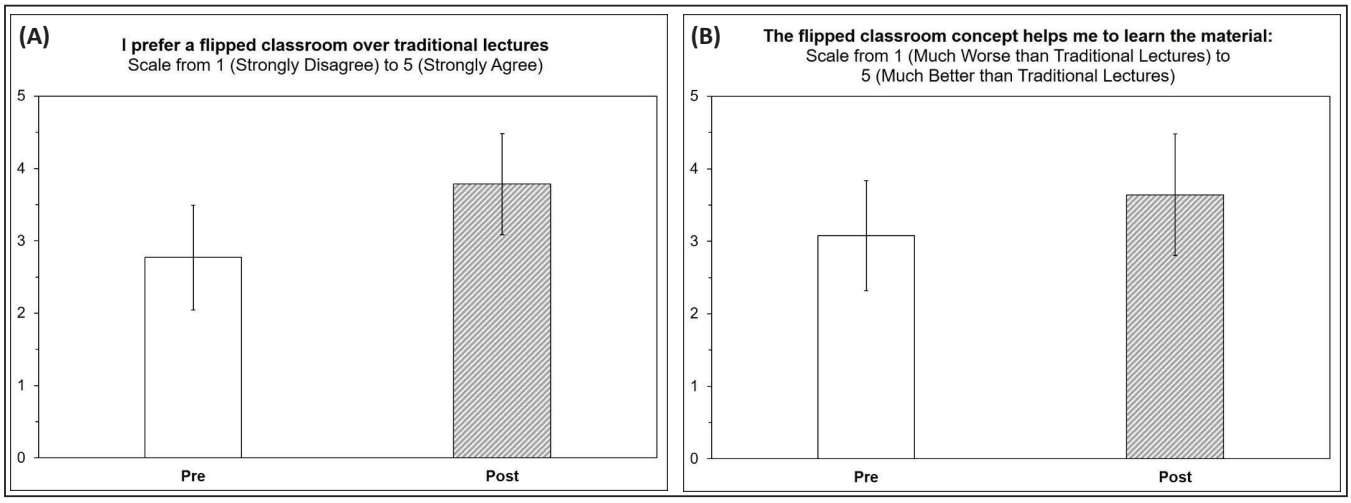

Figure 5. *Student survey results pre and post change from traditional lecture to a flipped classroom format. Higher average Likert values were observed in both (A) student preference and (B) perception of learning.*

Student written responses regarding what they liked about the flipped classroom are shown in Table 3. In summary, the most common response was that students liked getting to do many example problems in class, problems that would otherwise have been part of the homework set (8 responses). They also appreciated the shorter homework sets (5 responses), found the short lecture recap at the start of each class beneficial (4 responses), and liked the lecture videos that could be re-watched when necessary (3 students). Conversely, common student responses regarding what they disliked about the flipped class (Table 4) were consistent with other studies: more time required outside of class to watch the lectures that are due before every class (4 responses) and a preference towards traditional lectures with examples done step-by-step on the board (4 responses). Several students (3 responses) provided no negative comments concerning the flipped class. Interestingly, the ease and ability to ask questions were both a common like and dislike for students. A fair number of students (3 responses) felt that they had better opportunity to ask questions having encountered the material before the class period; it is likely that some students also felt more comfortable asking questions directly to the instructor in a smaller group setting, instead of out loud to the entire class. Conversely, an equal number of students (3 responses) expressed difficulty in asking questions, either because they did not know what to ask (since the material was not presented in real-time), or less time getting questions answered because many other students were asking questions.

DISCUSSION AND CONCLUSIONS

Overall, these results suggest that the flipped class resulted in consistent and sustained improvement in student exam scores relative to previous course offerings, which is a metric for measuring student learning in this class. This observation may be a result of several different factors. First, students learn the material throughout the entire week by watching the videos before each class period, rather than "cramming" over several hours, typically during the day before a homework set is due, or just before an exam. Second, working in class on example questions afforded students the opportunity to practice doing the problems, yet be able to ask questions right away when they get stuck on the problem. While these are the same problems that were assigned as homework in previous semesters, students now have immediate access to the instructor when they encounter questions. With a large number of students having access to online resources such as Chegg and solution manuals, the amount of individual student effort put into the homework is unclear, as well as how much learning was actually achieved from completing the assigned homework. Doing these problems as in-class exercises forces students to work through problems without the help of external resources. That the most common positive comment was associated with doing many examples in class is consistent with the common student feedback in prior semesters requesting more examples, feedback also observed by other instructors of this course at other institutions.[18] Third, the in-class exercises afforded students the opportunity to engage in collaborative learning as they work through these exercises together. Team-based learning (TBL) approaches have been shown to increase student retention, engagement, and performance.[19,20] While these in-class collaborative learning opportunities are different from longer-term projects that often characterize TBL approaches, the ad hoc formation of groups during class to work through in-class exercises facilitated interactions between students. I often witnessed students who successfully completed the

Table 3
Post-survey written comments regarding what students liked about the flipped classroom. Comments are copied verbatim from the survey.

List up to 3 things, if any, you liked about the flipped classroom method of instruction (be as specific as possible - what worked well?)
• Working examples in class really helps you understand the material better, you're able to find out immediately what you understand and don't. The review at the start of class allowed for an even better understanding after watching the video on our own.
• Getting to do more example problems helped me solidify what I learned better. It opened up more opportunity to ask questions about the material in class as well.
• I was exposed to the material earlier than usual.
• The lecture videos, homework in class, better understanding of the material/concept.
• It forced students to be proactive and self -independent to learn, and it made students have to really ask questions about what they do and don't know.
• Doing the examples in class was the best part, but I believe the only reason it was successful was because it was a small classroom and I could get direct help from the professor. Smaller homework sets was nice.
• I liked being able to hear the lecture repeated in class so I the things I struggled to understand could be clarified.
• More flexibility with class time, lectures could be re-watched, and I felt it was easier to see what I couldn't understand.
• I liked how many examples we did in class. Doing problems in class where it is easier to ask questions was very nice. I also liked how the homework was a lot smaller. I constantly had to go to office hours for help and it took a very long time to do and I had other classes I needed to focus on too. And I got to interact with fellow classmates more.
• I liked that the homework for each day was easy and I thought it was useful to go over all the examples we did in class.
• I really liked the ability to do examples in class. It helped me fully understand what to do. The less homework it lead to was also nice.
• I like your method of the flipped classroom where the videos are giving the same material as in traditional lecture. I also liked having lots of example time and shorter homeworks. I liked getting a brief overview of the lecture at the beginning of class.
• I liked that we could ask questions and work on homework in class ensuring that we were on the right path completing problems.
• I didn't like it but I didn't do any worse in the class.

Table 4
Post-survey written comments regarding what students disliked about the flipped classroom. Comments are copied verbatim from the survey.

List up to 3 things, if any, you disliked about the flipped classroom method of instruction (be as specific as possible - what did not work?)
• No complaints.
• It was a bit difficult to have to watch all the lecture videos outside of class. It was just another thing to remember.
• Less time getting my questions answered because so many students had questions.
• Never got through a whole example/finished it.
• Small review of the lectures, walk through a full problem together on the board like previously that way students can ask questions since it is harder because not all students can always make it to office hours.
• Sometimes I didn't have time for the videos.
• I felt it was harder to tell what things the class was struggling with as a whole as opposed to just myself.
• Sometimes the lectures being due every day could be a minor inconvenience but truly it wasn't a large problem.
• The videos were nice to do at home, but I feel like I learn better in person. So most of the material I learned how to do in class during the examples and not from the video. I also feel like I asked less questions than I normally did and would sometimes get stumped on a few parts during exams.
• It was a lot more work outside of class and I didn't understand the quizzes because our actual home work wouldn't cover what could be on it because the homework was very short.
• Not anything to mention.
• I feel like some material, especially earlier on in the course, is important to be taught traditionally.
• There wasn't anything I disliked about the flipped classroom.
• I didn't retain the class information as well.

exercise teaching others how to do the problem, as well as lively discussions when different students did not arrive at the same answer. Such engagement not only helps students learn the material better as they articulate their work to one another, but also fosters relationships between students. In several cases, students would not have been able to complete the problems without help from fellow students. It should be noted, however, that collaborative discussions during in-class exercises were encouraged but not mandated. Notably, a few students preferred to keep to themselves and attempted the problems on their own; this was especially prevalent with international and/or non-native speaking students who tended to keep to themselves.

From an instructor point of view, the flipped class has the advantage of allowing me to give quasi-individual attention to the students. In addition, common mistakes and questions as the students work through the examples provide real-time feedback on material that is confusing or challenging for most students. This provided me an opportunity to address the misconceptions right away with the entire class. In prior semesters, such valuable feedback was only made known to me after grading an exam, which would be too late. Conversely, classroom management is more challenging, as different groups of students work through the problems at different paces. This issue is especially tricky with students who either

did not watch the videos prior to class, or did not understand the material in the videos well enough to work through the in-class examples. These students tend to want to dominate my time in the classroom as they generally struggle even on the basic steps of the problems. As a result, I find myself in a dilemma of either spending more time with these students re-explaining the basic steps and concepts that were covered in the videos (at the expense of answering other students' questions), or walking away and putting the responsibility back on them to learn the material well through the videos (at the expense of "leaving them behind" for that class period). While the flipped classroom places the responsibility of learning the material on the students prior to class, it is my opinion that explaining and presenting concepts clearly, and demonstrating problem solving step-by-step, are still critical roles of an effective instructor. Student feedback suggests that the review of video lectures at the start of class as well as the summary of the in-class example problem at the end of class, segments that would be classified more closely with traditional lectures, were helpful towards their learning.

By far the largest additional effort to implement the flipped class is in the development of the videos. Between creating PowerPoint slides, filming, and traveling to the production studio on the University of Minnesota – Twin Cities campus, this endeavor to develop the entire suite of videos took over 160 hours (editing and uploading of the videos were done by the video production team). Informal feedback from students comparing videos from prior flipped classroom experiences indicate they appreciate the high quality videos that helped them learn the material well. Based on a study by Guo et al. regarding massive open online courses (MOOCs), students indicated informal talking-head videos and Khan-style tablet drawings were more engaging.[21] These findings are consistent with other studies such as Kizilcec et al., who found that students "strongly preferred instruction with the face and perceived it as more educational", and they spend "about 41% of time looking at the face and switched between the face and slide every 3.7 seconds".[22] Guo et al., however, also found that student engagement decreased with video length, with many students completing merely less than half of videos that were longer than nine minutes.[21] In my experience, trying to create videos that were under ten minutes long, while covering all the necessary material in depth, was practically impossible. In the end, a personal decision was made to forego video length limitation in favor of detail. There were no negative comments regarding the length of the videos; students appreciated that the video lectures mirrored a traditional lecture in terms of content and detail (see Table 3). In addition, from a survey of the students enrolled in the online version of this course in Summer 2018 (who watched the same suite of videos), none expressed that the videos were too long: 10 of out the 11 students thought the videos were the right length, with one student even indicating that the videos were too short and content too rushed. This difference in survey opinion from other published studies may be due to the nature of a formal course for credit required for completion of a degree program compared to MOOCs. There is greater pressure to learn the material well enough to demonstrate the proficiency and get good enough grades in tests and exams; hence, students may be more willing to sit and stay focused through longer videos. In addition, for a course such as MEB that emphasizes problem-solving skills, it is important for an instructor to demonstrate by example his/her thought process and methodology in working through the problems in a logical and systematic way, which is near impossible to be done in under ten minutes.

There are several limitations to this study, which should be considered carefully when interpreting the results. First, because of the addition of a recitation section in Fall 2016, only Spring 2018 had the same class setup for direct comparison with Spring 2019. Comparison of exam score trends between Spring 2018 with prior semesters, however, show no obvious improvement in exam score trends, which suggests that this extra recitation section had no significant effect on student learning, allowing for these semesters to be used to compare the effects of flipping the classroom. Second, there is only half a semester of data using the flipped class method for comparison with five full semesters based on traditional lectures. However, flipping the class midway through the semester provided the opportunity to compare student learning within the same class of students. Third, while statistical comparison of scores is done within the same cohort of students in the same semester, variability in difficulty of each exam between semesters may still exist, which cannot be quantified and accounted for easily. Fourth, the class size (17 students) was the smallest out of all the semesters, which afforded me the luxury of spending more time per student in class. It is unclear whether the flipped class would work as well with a larger class size, especially with the common negative feedback that too many students had questions for the instructor to answer fully all questions individually. Student comments indicate more skepticism that this method of instruction would work in larger class settings (see Table 3), presumably based on less positive experiences of flipped classroom instruction in large lecture courses such as General Chemistry II. One potential solution is to have the Teaching Assistant (TA) attend every class to help answer students' questions. In addition, further encouragement of collaborative learning could potentially ease the burden on the instructors and TAs, as students could help one another through the problems and arrive at the solutions collaboratively. Taken together, however, this trial semester has produced encouraging results in terms of student learning and engagement to try flipping the classroom for future semesters and other courses, as well as looking at other potential hybrid methods to cater to the wide array of preferred learning styles.

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